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ASSESSMENT (PORA)--
SYSTEM DEVELOPMENT
AND PRELIMINARY FINDINGS

KFR 287-80

10 September 1980

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EXECUTIVE SUMMARY AND CONCLUSIONS

In this project, Ketron developed a pilot Performance Oriented Readiness System (PORA) for the A-7 and F-14 aircraft under the sponsorship of COMTACWINGSLANT. The work consisted of three major elements:

1. Construction of the basic framework of an A-7 PORA,
2. Construction of the basic framework of an F-14 PORA, and
3. Conduct of a five-month test of the A-7 PORA with two squadrons.

We identified data sources to support A-7 and F-14 PORA and built operational sequence models for the primary missions of these two aircraft: these form the analytic machinery of PORA. We then used the models and the available data to produce PORA reports. These computerized reports were distributed to the two A-7 squadrons participating in the PORA test and to COMLATWING ONE. Discussion of the first set of PORA reports with the squadron and wing personnel led to refinements in the analytic models and report formats. A second set of reports, reflecting these refinements, was sent to the squadrons with data through May 1980.

A-7 PORA

The A-7 PORA system concentrates heavily on two areas of performance. First, it relates a squadron's sortie generation capability to aircraft availability factors. The sortie generation model is flexible, and it can tailor its

estimates to each of a wide variety of schedules and missions. Second, the PORA system relates the individual pilot's expected target killing capabilities to bombing scores achieved on training ranges. It also exploits known learning curves to project performance estimates into the future and relate performance to level of training. Finally, the PORA system combines the squadron sortie generation capability with its weapon delivery accuracy to estimate the basic measure of a squadron mission performance, targets killed per day.

At its present stage, the A-7 PORA system concentrates on reports most useful at the level of the individual pilot or the squadron commanding officer. It compares pilot and squadron performance to fleet averages, and in doing so it suggests possible reallocations of training resources.

F-14 PORA

The F-14 PORA methodology follows the general lines of the A-7 PORA. The same sortie generation model works for the F-14 as well as the A-7. The same type of aircraft availability data feeds the model, which can project an F-14 squadron's sortie generation capabilities for a variety of schedules and missions. Two mission areas are considered in the F-14 PORA scheme, force defense against attacking bombers and raid escort against attack fighters; and performance measures were developed for both missions, i.e., intercept performance in force defense and exchange ratio in raid escort. Finally, the PORA system combines the sortie generation with the performance measures to derive measures of squadron mission performance i.e., bombers destroyed and the exchange ratio against fighters. There was no test of the F-14 PORA to assess the readiness of a specific squadron in this pilot project. However, our initial investigation in-

licated that the data to assess F-14 performance are scarce compared to data on A-7 performance. The F-14 usually cannot receive quantitative scores for its training activities (comparable to the near-daily bombing scores that attack aircraft receive from raked ranges). Typically, a fighter squadron participates in one ACM exercise at the TACTS during each turnaround training cycle. F-14 participation in the SEABAT intercept exercises is less frequent. Thus, performance data may accumulate too slowly to track the progress of individual aircrews. The F-14 PORA developed here thus concentrates more heavily on the aggregated performance of a squadron.

LEARNING CURVES

An important facet of PORA is to develop fleet performance levels and learning curves. These serve as standards against which squadrons and individual aircrews may compare themselves. The learning curves provide a means of projecting future performance estimates from present performance levels. Because learning curves also relate the improvement in performance to readiness resources (flight hours, number of bombing runs, practice ACM engagements, etc.), they are a tool for adjusting training resources.

Our A-7 PORA test was too brief to produce definitive learning curves. The accumulation of more data and from more than two squadrons is required to support learning curves that can be useful for these purposes.

In the F-14 PORA we have already started to make estimates of the learning acquired by squadrons during their exercises at the TACTS. We anticipate that other learning effects will become apparent when the F-14 PORA is tested.

CONCLUSIONS

In a pilot study such as this, it is difficult to reach firm conclusions about readiness itself -- but we can provide some conclusions about the PORA system:

- There is ample weapons delivery data to support the A-7 PORA;
- The A-7 PORA can translate aircraft availability factors to a squadron's capability to meet mission requirements;
- The A-7 PORA system is readily adaptable to an A-6 PORA;
- The F-14 PORA is feasible, but not to the same degree of detail as the A-7 PORA;
- The F-14 PORA system is readily adaptable to an F-4 PORA;
- The PORA system can help the operational commander determine the amount of training required to maintain the basic aspects of proficiency;
- The historical data base being generated by PORA gives quantitative fleet performance standards based on actual data; and
- The delivery accuracy data needed by A-7 PORA duplicates much of the records now maintained manually by the squadron WOs. PORA can provide this information to the squadrons on a timely basis, and reduce the paperwork burden on fleet personnel.

INTRODUCTION

This is the Ketron Final Report on its pilot project to develop a Performance Oriented Readiness Assessment, PORA, for the Commander, Tactical Wings Atlantic (COMTACWINGSLANT) under contract number NO001480-C-0232.

This report includes the following deliverables:

1. A description of the A-7 PORA approach, its operational sequence model, supporting mathematical models, sources of requisite data, and output report formats;
2. A description of the F-14 PORA approach, its operational sequence model, supporting mathematical models, sources of requisite data, and output report formats; and
3. Results of the initial test of the A-7 PORA system on two squadrons. A set of report formats was sent to each of the squadrons that participated in the PORA test.

The report is broken down into three main sections and a set of five appendices. An overview of the PORA concept is first presented, detailing how the present effort ties into the larger context of Fleet readiness. A description of the A-7 PORA follows and presents the A-7 operational sequence model, measures of effectiveness, data, and finally the PORA report generated for the two test A-7 squadrons during a five month test period.

The last section of the text is concerned with the F-14 PORA. Again, the operational sequences, models, measures, and data are discussed. PORA report formats are then addressed, but no squadron test data is presented.

The appendices contain much of the background material for the text. Appendices A and C discuss the A-7 and F-14 PORA methodology respectively. Appendix B gives an overview of the sortie generation model, used in both the A-7 and F-14 PORA methodologies. A-7 bombing data, i.e., histograms of CEPs by bombing mode, are presented in Appendix D. A full set of PORA reports for the two test squadrons is contained in Appendix E. This appendix is, however, not included in the report; it is available under separate cover upon request to COMTACWINGSANT.

THE PORA CONCEPT

This section describes the Ketron approach to a readiness management information system. The approach is based on the prediction of performance for units in expected combat situations. Using this approach, it is possible to tie together the various components of readiness, i.e., missions, people, training, aircraft, parts, weapons, ground support equipment, services, and dollars into an integrated assessment of the ability of a particular combat unit to perform its primary missions.

Much of the data required for such an integrated readiness information system is already collected by the Navy and is reported to commanders at various levels in different formats. However, this information is not developed into an overall assessment that highlights the important readiness factors and problems in a reasonable and balanced way. Ketron submits that a performance-oriented readiness assessment (PORA) system provides the balance and scope required for effective readiness management.

The heart of the PORA concept is an operational sequence model whose output is performance and whose inputs are the various readiness resources, i.e.:

- aircraft (number, type, and availability),
- pilots/NFOs (number, training status, performance),

- maintenance personnel (number, type, experience), and
- weapons (availability, reliability, lethality, and numbers).

Rarely are complete sets of data available on the ability of a unit to perform its combat missions. The operational sequence model allows use of partial data on unit training performance (which is all that is normally available) to estimate combat performance. The predicted performance is, of course, dependent on the mission to be performed and on the threat specifics. Clearly for a standardized readiness information system, a standard threat or set of threats must be postulated in order to evaluate own force performance.

The resources that go into maintaining and improving readiness are funds, range services, flight hours, training, ordnance, carrier time, spare parts, and ground support equipment. These interact with the mission, threat scenario, and performance data via the operational model as depicted in Figure 1. Thus in its final form, the PORA system would identify the resources required, (i.e., the amount of time and services), to bring specified units up to full combat readiness.

Two other aspects of the proposed approach to readiness management should be mentioned. First, many of the readiness reports and formats are computerized for rapid updating and dissemination of readiness information. It is of particular importance to provide rapid feedback to the units supplying the readiness data as to their readiness status and projected performance. Second, it is equally important

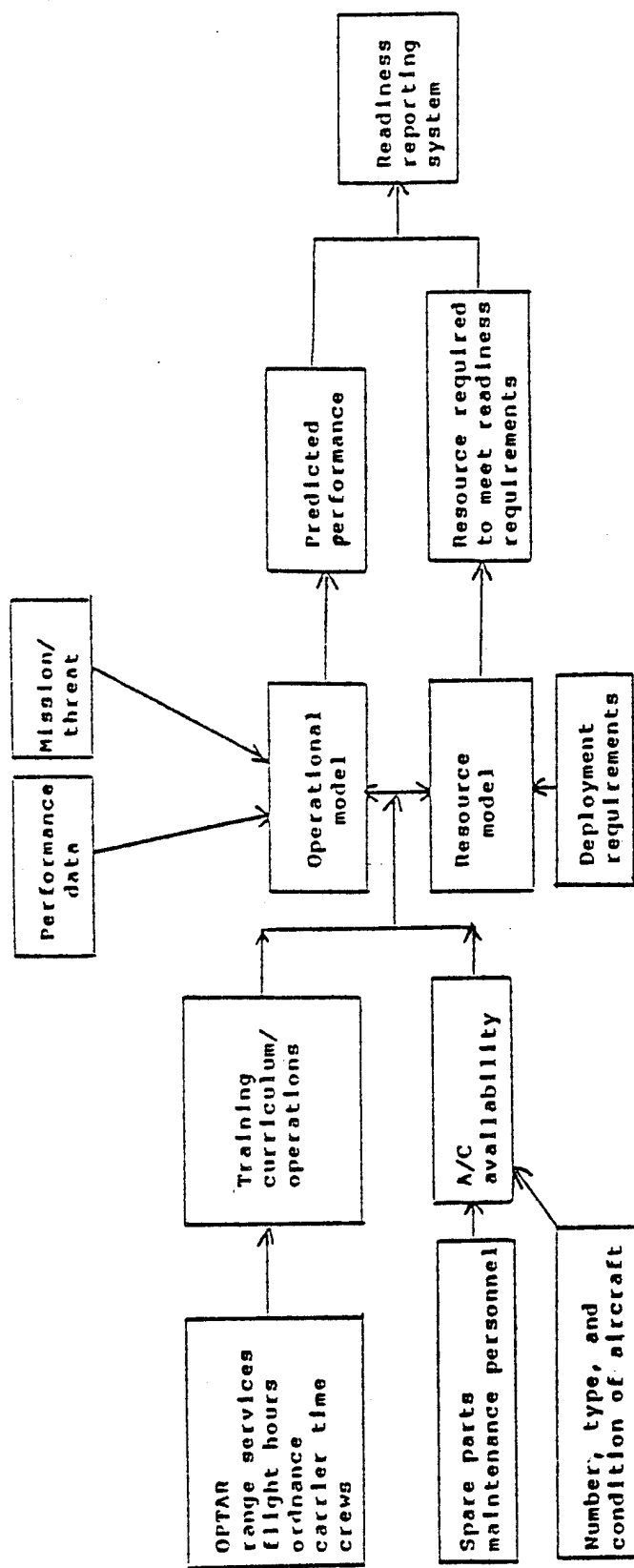


FIGURE 1: SCHEMATIC OF A PERFORMANCE ORIENTED READINESS
MANAGEMENT INFORMATION SYSTEM

not to saddle the operating commanders with additional reporting requirements. Ketron's approach here uses:

- current readiness reports to the maximum extent possible and
- Ketron personnel to collect required data in lieu of tasking the unit.

This, then, is the general concept of the Ketron readiness management information system. It incorporates what we consider to be the three primary aspects of a readiness information system:

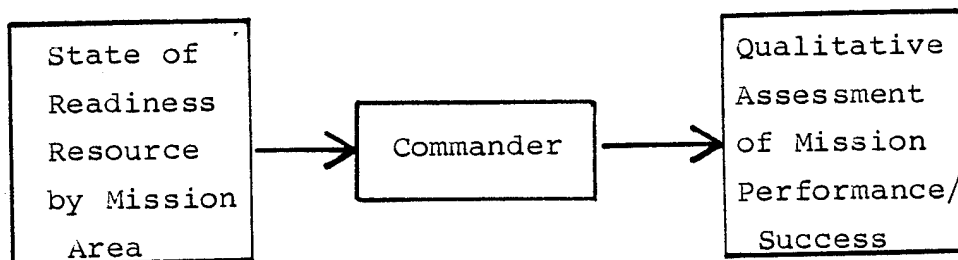
- to predict mission performance,
- to spot readiness problems easily, and
- to provide feedback on the effect of actions on overall readiness.

In the present study, we have not taken a detailed look at all of the readiness resources. For example, a complete modeling of the spare parts and maintenance personnel impact on readiness would be much too burdensome and expensive at this early stage of POR. Other resources, such as time in the training cycle, and the number of practice bombing sorties are examined closely; however, a larger historical data base is needed before the effects of these resources can be fully evaluated.

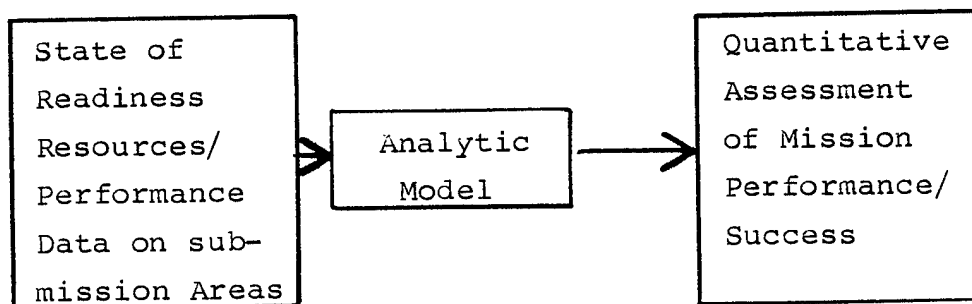
It is of interest to compare briefly the performance oriented readiness assessment approach to the readiness reporting systems in use today.

The current UNITREP system and the older FORSTAT system collect information on the state of readiness resources i.e., people, training, supply, material, and equipment. They assess the state of the resource against some standard in order to assess readiness in each area. Mission readiness is determined by the state of resources supporting that particular area. This assessment is made qualitatively and

results in a determination in one of 4 readiness states: fully combat ready (C-1), combat ready (C-2), marginally combat ready (C-3), and not combat ready (C-4). While the current system addresses in some detail the readiness resources, it does not address mission performance, or the likelihood of success in a combat situation, which, of course, is the ultimate intent of any readiness system. The link between states of resources and expected performance in a mission is made subjectively by the individual commander. Schematically we can represent this process as :



The PORA approach, on the other hand, addresses mission performance directly -- linking resources and partial performance measures to estimates of mission performance via an operational sequence model, i.e.:



The result is a quantitative estimate of mission performance and a quantitative link between readiness resource and performance.

It must be noted that the newer UNITREP system is more performance oriented than FORSTAT. UNITREP reflects training opportunities and some scores achieved by aircrews. However, it is an X-in-the-box type of system. For example, for a delivery mode in which a 46 meter CEP is a qualifying score and a 23 meter CEP earns an E, an aircrew achieving a 46 meter CEP may be considered fully qualified for six months. An aircrew scoring 25 meters may be considered no more qualified than the 46 meter crew. However a crew with a 47 meter CEP may be considered unqualified. In reality, the proficiency of the crew scoring 46 meters is much more nearly like the unqualified crew than like the crew with the 25 meter CEP.

The PORA system uses smooth, or continuous, measures of performance and updates the performance measures of aircrews or squadrons at every opportunity. Thus, the PORA indicates improvement or degradation in performance. It also projects future performance by considering readiness resources and learning curves and calculates estimates of mission performance in operational scenarios.

Finally, the PORA system accumulates as a by-product a historical file of performance measures and calculates fleet averages and percentiles of performance from this data. Trends in mission performance can be established and tracked over time.

In summary, the PORA approach can be viewed as complementary to the current readiness system, providing quantitative performance estimates where the current system provides none. The UNITREP system, alternatively, provides a good deal of structure to assess readiness resources, identifies deficiencies, and directs corrective actions.

A-7 PORA

MISSIONS

The A-7E is the standard light attack aircraft in the fleet today. It is a single-seat aircraft capable of carrying a wide variety of air-to-ground and air-to-air weapons. The A-7E's navigation/weapon delivery system and head-up display give the pilot capabilities not available in earlier light attack aircraft.

Two A-7E squadrons are included in every carrier air wing. With an A-6 medium attack squadron, they comprise the air strike capability of today's carrier battle groups.

COMNAVIAIRLANT's Air Wing Readiness Training Manual lists the primary mission areas for light attack squadrons with the following weights:

AAW: Anti-Air Warfare	10%
ASU: Anti-Surface Ship Warfare	20%
STW: Strike Warfare	35%
AMW: Amphibious Warfare	5%
MIW: Mine Warfare	5%
MOB: Mobility	20%
CCC: Command, Control and Communications	5%

Three of the missions (ASU, STW and AMW) carry 60% of the total weight. These missions all focus on the delivery of air-to-surface ordnance. Additional credit for the delivery of air-to-surface ordnance is given within the MIW and CCC missions. Finally, the mobility "mission", carrying a weight of 20%, does not compete with the other missions, but

is required to carry out these other missions. Therefore, the ability of a squadron to generate sorties that can locate and attack surface targets reflects most of the weight assigned in COMNAVAIRLANT's Manual.

The present PORA system, therefore, considers the attack on surface targets (on land or at sea) to be the primary mission of the A-7E. Accordingly, the principal measures of performance in this report reflect the A-7's capability to fly against and destroy surface targets.

In this initial PORA effort, AAW, MIW, and CCC are considered to be secondary missions of the A-7E. Collectively, they carry about 20% of the total weight assigned in COMNAVAIRLANT's Air Wing Readiness Training Manual and receive only light attention in this pilot project. They will receive additional effort in future PORA work.

OPERATIONAL SEQUENCE MODEL FOR THE A-7

An operational sequence model is the key to PORA for any combination of weapon system and mission. The operational sequence model is a flow diagram of the steps that must be followed for a successful mission. For the A-7, we focus on the attack mission for aircraft.

Figure 2 is a simplified diagram of the operational sequence model used by the PORA system for the A-7 attack mission. As the first step, we see that the squadron must generate attack sorties. In the next step, the air crew must fly the aircraft to the target and identify it correctly. In the third step, we are concerned with the aircrews' ability to deliver ordnance on the target, once identified. Then, if all of the prerequisites have been met, we tally a success.

There is fine structure inside each of the steps or

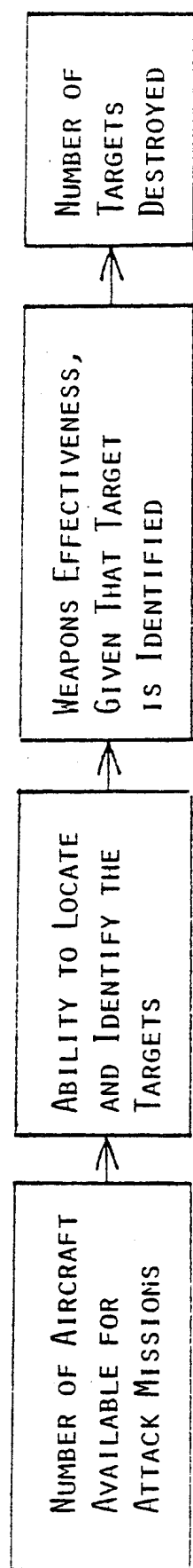


FIGURE 2: SIMPLIFIED OPERATIONAL SEQUENCE MODEL FOR ATTACK MISSIONS

boxes of Figure 2. Figure 3 shows some of the more detailed considerations for the sortie generation estimates; Figure 4 shows some of the detail for weapons effectiveness calculation; while Figure 5 shows how the results of each step in the sequence are combined to obtain a final measure of combat performance: target killing potential. A more detailed description of the mathematical models relating to weapon effectiveness is given in Appendix A. Appendix B provides a mathematical description of the sortie generation model.

MEASURES OF PERFORMANCE FOR THE A-7

The primary missions for the A-7 aircraft involve attack with air-to-surface ordnance. Therefore, the primary measures of performance (MOPs) for the A-7 are concerned with its target killing capability. For example, our principal combat measure for an A-7 squadron is the number of targets killed per day. This measure integrates the squadron's capability to generate attack sorties, its ability to locate and identify targets, and its weapons delivery accuracy.

The PORA system uses several MOPs. Some are useful to the individual pilot, some are useful at the squadron level, while other non-aggregated MOPs are useful at the wing or higher levels. The following subsections discuss these MOPs; Appendices A and B provide the supporting mathematical descriptions.

MOPS for the Individual Pilot

There are two measures of performances considered by PORA for the individual pilot, weapon delivery accuracy and target location and identification.

The weapon delivery accuracy of each pilot is a fundamental measure of performance for PORA. There are several

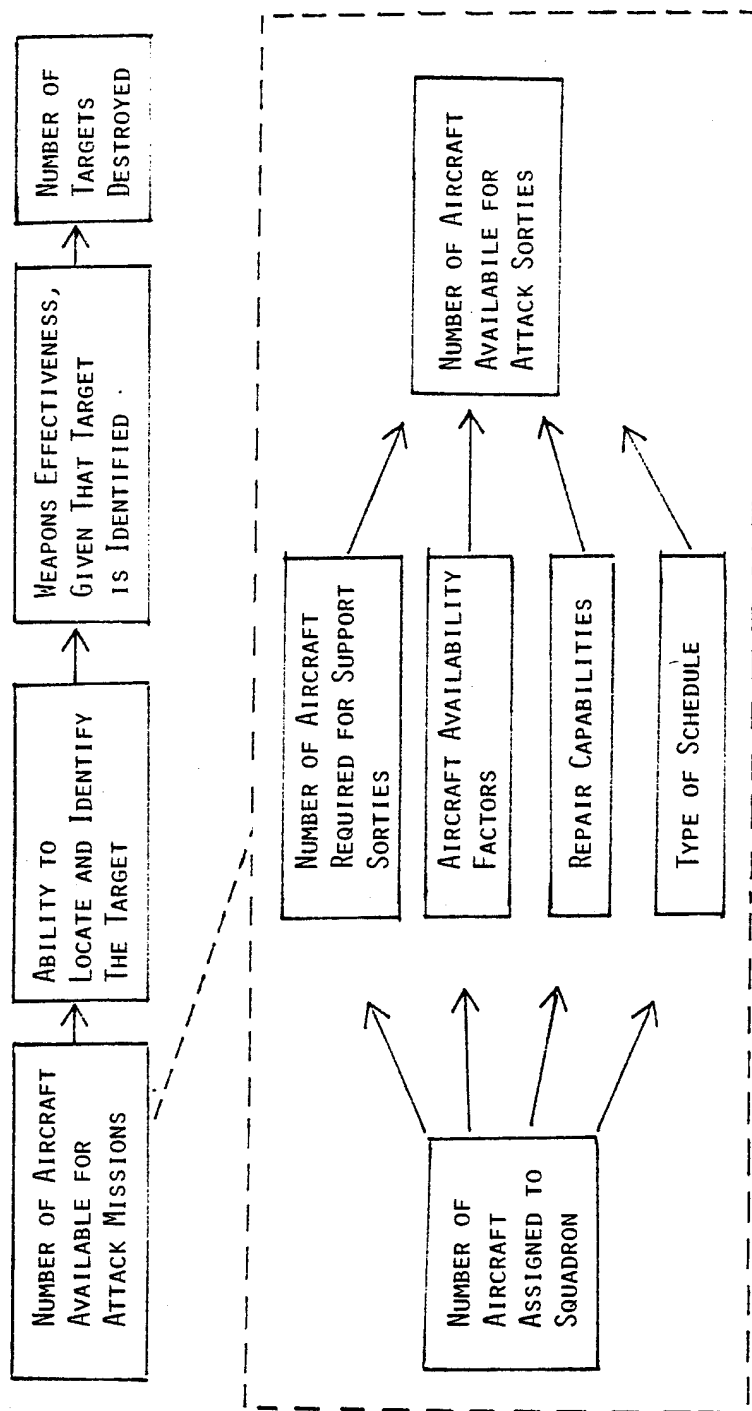


FIGURE 3: OPERATIONAL SEQUENCE MODEL FOR ATTACK
MISSIONS - SORTIE GENERATION

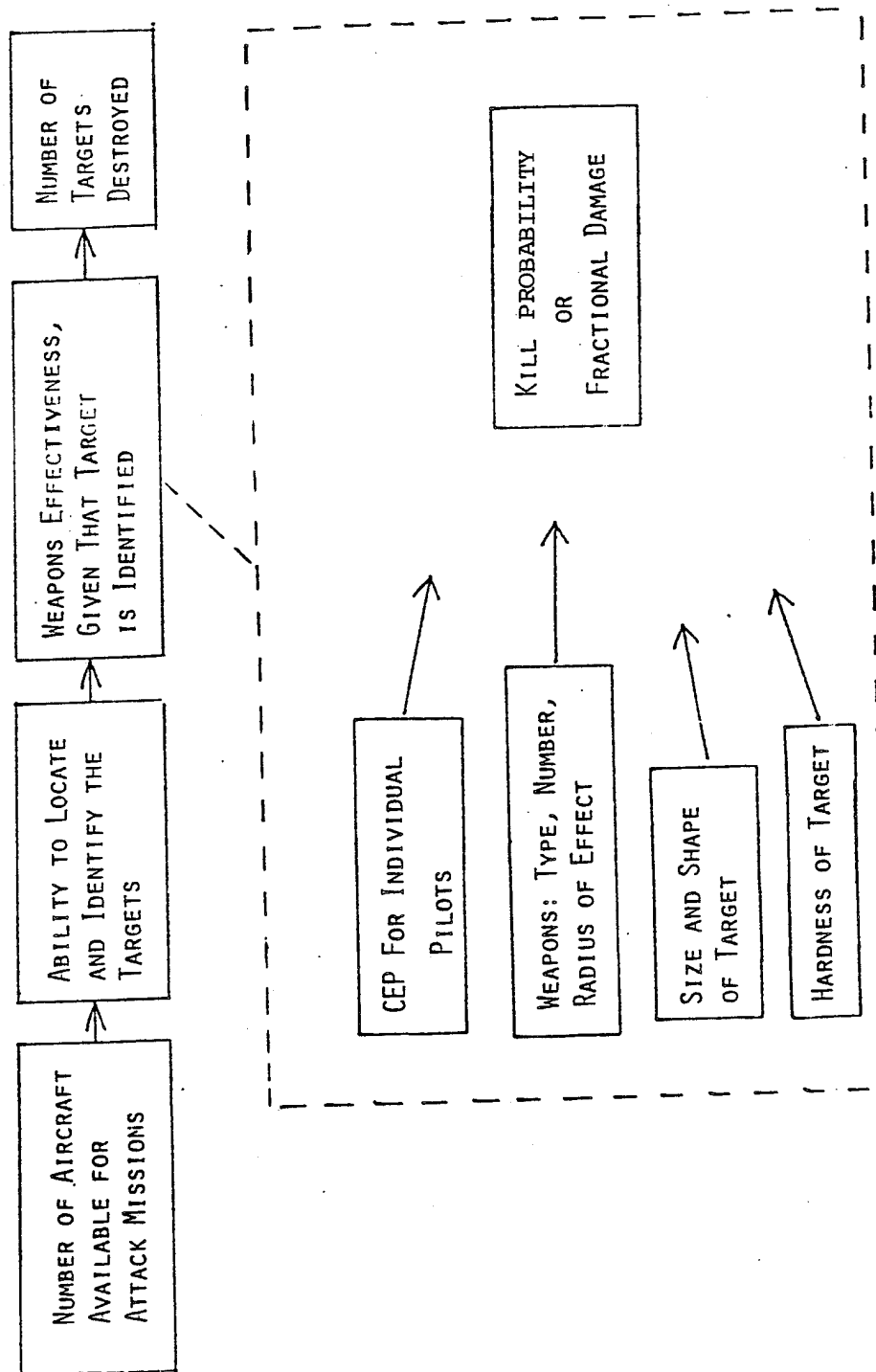


FIGURE 4: OPERATIONAL SEQUENCE MODEL FOR ATTACK MISSIONS - WEAPONS EFFECTIVENESS

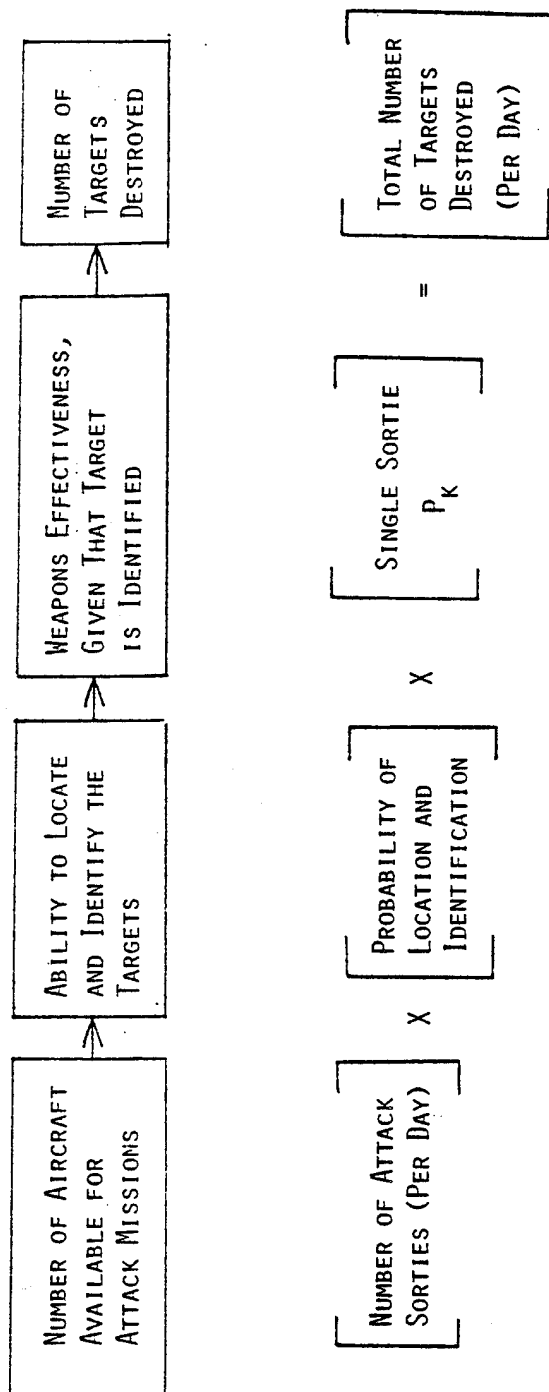


FIGURE 5: OPERATIONAL SEQUENCE MODEL
FOR ATTACK MISSIONS - PRODUCT

types of delivery for air-to-surface ordnance. The PORA system uses delivery accuracy statistics for each of the following delivery modes (with FXP-2 exercise designators):

- A-4-R Rockets
- A-6-R Day Dive Bomb
- A-6-R(N) Night Dive Bomb
- A-7-R Minimum Altitude
- A-8-R Laydown
- A-9-R Radar Bombing
- A-10-R Pop-Up
- A-11-R Roll Ahead
- A-12-R Over-the-Shoulder
- A-14-R Loft

We have accumulated accuracy data for all of these delivery modes over a five-month period for two squadrons. These data have been used to estimate the CEPs for each delivery mode for each pilot in the squadrons. The bulk of the data is, however, on day dive and night dive bombing modes and the initial PORA project has focused on these delivery modes for much of the report generation; i.e., we have used the CEPs for these modes to estimate the single-sortie kill probability, P_k , against a variety of targets.

In addition to calculating the raw CEPs, the PORA system compares the delivery accuracy scores to a historical learning curve, (See Annex A-4). In this way, it can be determined whether a pilot's bombing performance is above or below fleet or squadron averages. PORA then projects the pilot's future performance along a tailored learning curve, calculated from his own accuracy statistics, but generally parallel to the standard fleet learning curve.

The PORA system also assigns to each pilot a

probability of successful navigation, target location, and target identification. This MOP is a function of visibility conditions (day or night, good or bad weather), the flight profile of the mission, and the nature of the target (prominent bridge or buildings, or troops or vehicles under vegetative cover). This MOP is based on the profile training exercise A-20-R.

MOPs for an A-7 Squadron

The primary performance measure for the A-7 squadron is the number of targets killed per day. PORA estimates this measure by multiplying the following quantities together:

- the number of attack sorties that the squadron can launch per day,
- the probability that a given sortie locates the target, and
- the kill probability of each sortie that reaches the target.

Each of these quantities is a squadron MOP by itself. Their combination provides the primary measure of squadron performance.

The measures of a squadron performance reflect the capability of its pilots (in aggregate) to navigate to the target, locate and identify it, and deliver ordnance accurately. These individual pilot MOPs are incorporated in the reports sent to the Commanding Officer. PORA also provides the commanding officer with the average performance (or a distribution of the scores) for all squadrons. Thus, he can compare the performance of his squadron against fleet norms.

A squadron's performance includes more than the aggregate contributions of its pilots. The squadron must provide mission ready aircraft, in addition to capable pilots.

Thus, sortie generation capability is the third important MOP for a squadron.

A PORA sortie generation model has been developed to estimate this capability. It determines the expected number of sorties that can be flown per day by an individual squadron. This model is fully described in Appendix B. A primary input to the sortie generation model is the aircraft availability factor for the squadron. The required level of availability (mission capable, full mission capable, etc.) varies between missions. The model uses the factor for the availability level appropriate to the mission. A squadron may be required to fly several types of missions, each requiring a different level of availability. The sortie generation model requires as inputs the types of missions to be flown, the priority of each mission type, the structure of the schedule (deck cycle time, etc), and the availability factors. From these, the model produces estimates of the number of sorties, by mission type, that may be expected from a squadron. These sortie generation estimates are important MOPs in their own right. However, they are only components of the squadron's primary MOP: its daily target killing capability.

If a squadron had only one type of target to attack, the squadron MOP would be quite simple to calculate. In practice, the situation is more complicated. Each pilot has a distinct CEP and, hence, a distinct P_k for a given target. Additionally, a squadron normally attacks several different types of targets. The PORA system accounts for these complications by using an average P_k for each target type and by using a number of target mixes.

The target mixes used by PORA are composed of the typical targets for which the pilots' P_k s have been

calculated. For the purposes of this report, the target mixes have been selected without reference to specific theaters of combat. We have chosen three mixes: one composed largely of small hard-to-hit targets, one composed largely of large targets, and one intermediate mix. In future PORA work, we will use target mixes that reflect typical targets from scenarios of interest. For example, one target mix will be composed of targets likely to be attacked in a NATO war and another mix will reflect a Middle East scenario. Other mixes may reflect scenarios such as an attack on Soviet ships at sea or a war in Cuba.

MOPs for the Wing and Higher Levels

The functional wing commander and the carrier air wing commander have broader interests than the squadron commander and the pilot. The wing commanders need not concern themselves with the proficiency of individual pilots but may wish to compare the performance of squadrons under their command to each other, to fleet-wide performance levels, and to "required" combat standards. They may also wish to examine the performance estimates for a carrier air wing, especially in regard to scenarios associated with forthcoming deployments.

The MOPs of interest to the wing commanders are then the relative target killing capabilities of individual A-7 squadrons and the combined target killing capability of the two A-7 squadrons in an air wing.

At the COMTACWINGSLANT and COMNAVAIRLANT levels, the measures of performance are more highly aggregated. These commands should see MOPs similar to the squadron level MOPs, but combined for the entire attack component of an air wing. The PORA reports highlight deficiencies (e.g., need

to improve sortie generation, need to improve night performance, etc). Other PORA reports will relate readiness resources (spare parts, flight hours, time on the bombing range, etc.) quantitatively to performance levels. However, these reports await the accumulation of a historical data base. When the reports are available, commanders will be able to assess the improvement in combat performance of the squadron(s) receiving additional readiness resources. These commanders will also be able to assess the negative impact on the performance of donor squadrons if the resources are in limited supply or constrained by budget.

The results projected by PORA reports will be of assistance to higher level commands such as CINCLANTFLT and OPNAV. These commands must consider questions such as:

- Can we expect to destroy target mix X in the first ten days of a NATO war with carrier group A?
- How long will it take to neutralize target mix Y if we must attack targets in the Middle East?
- What are our capabilities against target mix Z, consisting of Soviet ships at sea?

The pilot, squadron and wing level PORA reports provide the basic performance inputs to generate answers to these questions.

DATA SOURCES FOR A-7 PORA

The discussion of data sources is arranged to follow the operational sequence model. We first discuss the data that supports the sortie generation model. Then we turn to data concerning navigation and target identification. Finally, we discuss the data concerning weapons delivery accuracy.

Most of the data on A-7 performance is available in one form or another. Some of the data is in official reports and other data is found in internal squadron records. We were able to produce PORA reports during the test period without imposing special reporting requirements on the two participating squadrons. There are, however, some inconsistencies in the way internal data is kept by the two squadrons. Standardized internal report forms or the use of raw weapon delivery scores would avoid "apples and oranges" comparisons.

As a side benefit to the PORA approach, the fast turnaround of data by PORA can reduce the paperwork chores within the squadrons while providing the desired consistency. In particular, the PORA machinery can assist the Weapons Training Officer in his data recording and calculations.

Data For Estimating Sortie Generation Capability

The sortie generation model used by the PORA system is described in detail in Appendix B. Data are required to support several of the inputs:

- aircraft availability rate (start of day),
- probability that a returning aircraft is downed for maintenance, and
- cumulative probability of repair for downed aircraft.

We address the data supporting each of these items in turn.

The number of aircraft on-board is normally 12 for an A-7E squadron. Records provided by COMLATWINGONE for calendar year 1979 show that the average fleet squadron possessed 11.75 aircraft while deployed, and 11.41 aircraft

while in a non-deployed status. The 11.75 average value seems appropriate for long range projections of combat performance. However, the actual number of aircraft possessed by a squadron is a better input value for short-term projections.

The start-of-day availability rate is available in morning reports. However, collecting all of these reports would be a burden on the operating fleet and a laborious process to PORA analysts. The Subsystem Capability Impact Reporting (SCIR) system gives average availabilities sampled at 30-minute intervals throughout the 24-hour day. The sortie generation model allows the calculation of the average start-of-day availability from SCIR data (see Annexes B-2 and B-3).

There was no readily available data on the probability that a returning aircraft is downed for maintenance. As the SCIR system becomes more fully developed, it may be possible to obtain the required data. This value undoubtedly varies from squadron to squadron. We investigated values .15 to .20. This range of values is consistent with those used by the Center for Naval Analyses (CNA) in the recent Sea-Based Air studies. The results are generally insensitive to input values in this range, with a squadron's daily sortie generation capability varying by less than one sortie.

The cumulative probability of repair data are also taken from CNA's Sea-Based Air studies. CNA representatives aboard aircraft carriers in both the Mediterranean and the Western Pacific recorded data for a variety of high performance aircraft. The data were taken at 105-minute intervals (coincident with aircraft launch cycles). These multi-source data were aggregated to produce a probability-of-repair histogram. There was a negligible probability that a

downed aircraft became available for the first launch following its recovery. However, 11% were available for the second launch, an additional 55% for the third launch, 10% for the fourth launch, 5% for the fifth, and 5% for the sixth. Additional data were recorded about 15 hours after the aircraft were downed, and another 4% of the aircraft had returned to an available status (cumulative repair of 90% of downed aircraft). The sortie generation model uses these data for schedules with 105-minute deck cycles, and the model interpolates between these points for other schedules.

Data For Sortie Generation with Multiple Missions

The preceding discussion might imply that aircraft availability is a simple choice, i.e., the aircraft is available or it is not. Aircraft availability data actually contain several levels of availability. The A-7 may be called upon to fly various missions, each requiring a different level of availability. The PORA sortie generation model can handle a schedule with multiple missions and multiple required levels of availability. We illustrate a two-mission, two-levels-of-availability sortie generation example in the F-14 section of this report.

The SCIR system is still relatively new, and it does not currently report in the detail that the data are recorded. However, future SCIR will give the availability factors in greater detail than merely Full Mission Capable (FMC) and Mission Capable (MC). The data in SCIR can determine A-7E availability in the following levels (OPNAVINST 5442.4F):

- A - Optimum Performance Capability
- B - Strike
- C - Strike Support

- D - Visual Attack
- J - Expanded Mobility
- K - IMC Flyable
- L - Safely Flyable
- Z - Not Safely Flyable

FMC category comprises levels A and B. The MC category embraces levels A through D. When the SCIR system starts to report availability in these finer levels, the sortie generation will relate the levels to mission requirements and calculate multi-mission sortie generation capability.

The final "scrubbed" statistics from the SCIR system are published two to four months after the reporting month. However, preliminary SCIR data are available to each squadron about a week after the end of the reporting month. These preliminary data will provide the requisite aircraft availability statistics for the sortie generation model.

Data For Estimating The Probability of Successful Navigation and Target Location and Identification

The probability of successful navigation and target location and identification is poorly supported by existing data. The A-20-R exercise is the only source of data that we could find for this factor. Unfortunately, only a limited number of A-20-R exercises are conducted. COMLATWINGONE provided data for all such exercises in 1980. As of early May, only 20 such exercises had been run, and only two pilots had points deducted for navigational problems. The sparse data fail to help us distinguish between pilots or even squadrons in navigational proficiency. Thus, we can only estimate a probability of .9 for all squadrons in the navigation phase of the operation sequence models when the mission is similar to the A-20-R.

This .9 probability is strictly applicable only for missions flying the same profile used in the A-20-Rs, i.e., a low-altitude run-in to the target. Many attack missions are conducted at medium or high altitude, when the navigation is easier than in the A-20-Rs. For purposes of this report, we have thus assumed a probability of .95 for attack missions.

The A-20-R exercise is conducted in daytime when the weather is above specified minimums. For missions scheduled at night or during a season of bad weather, a degradation factor must be applied. Other degradation factors must be applied for moving or obscure targets. Until additional data is collected under these conditions, the degradation factors will have to be selected judgmentally.

Data For Estimating Weapons Delivery Accuracy

Squadron records contain much information regarding weapons delivery accuracy on the ten bombing modes noted earlier. Each squadron has a Weapons Training Officer who records data for every practice ordnance delivery sortie by each pilot. On the other hand, there is no existing data base for the average fleet pilot's bombing accuracy and learning curves for this initial PORA project. Therefore, we have used the historical squadron data shown in Figure 6. For the purposes of this project, these data have been treated as "average fleet performance". The performance of a single squadron during a single turnaround training cycle must not, of course, be taken as a definitive fleet average. However, these limited data will be augmented continually as the PORA system accumulates data from all squadrons and the estimates of the fleet average will continue to improve.

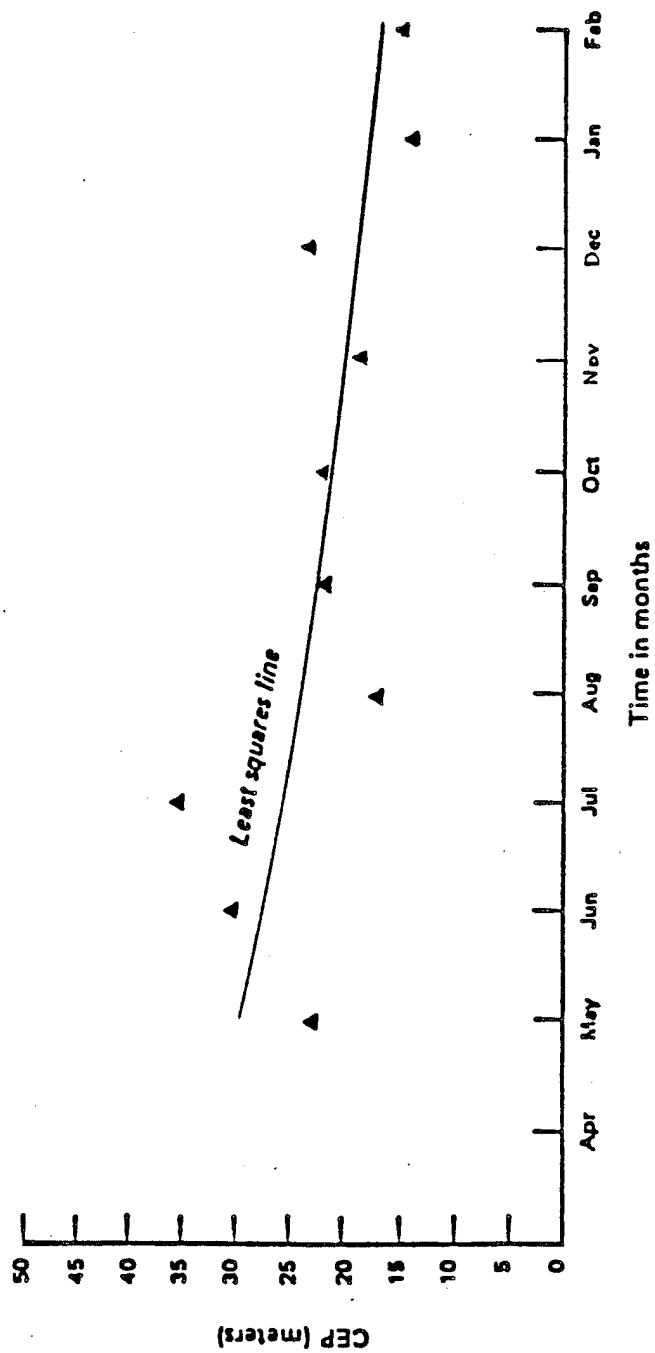


FIGURE 6: "AVERAGE" SQUADRON WEAPONS
DELIVERY LEARNING CURVE

There are differences in the way the test squadrons record the bombing data for internal squadron use. One of the squadrons in the A-7 PORA test records only the CEP for all of the delivery passes in a sortie. The other squadron records each individual miss distance (with the first pass data flagged). However, the second squadron makes no record of the date of each miss distance measurement; only the month is known.

In this pilot project, we were able to accommodate these minor inconsistencies; however, the inclusion of additional squadrons and further inconsistencies could negate the possibility of making valid comparisons. The "first bomb" scores are probably the best indicator of combat performance, when multiple passes will be the exception rather than the rule. If all squadrons were to provide first bomb scores, the inconsistency that arises from a varying number of passes per sortie would be avoided.

The absence of dates on the second squadron's summary records creates some problems in estimating its learning curves. Fortunately, the data are identified by month, so the delivery accuracy scores could be sorted into approximate chronological order. Provision of cumulative CEPs on the data sheets enabled us to narrow down the chronological uncertainties further.

Ketron does not recommend that additional paperwork be imposed on the fleet squadrons. However, it would be helpful if all of the squadrons were requested to record their data in the same manner. We believe that "first bomb" statistics would be most useful, but any standardization of format would be helpful.

The PORA system can, in fact, reduce the paperwork

chores of the squadron Weapons Training Officers (WTOs). It has already demonstrated its ability to list raw scores and CEPs of pilots in various weapon delivery modes (see the following RESULTS section) and to compare individual pilot's scores with fleet norms. This part of PORA is done on a computer. If the raw scores, now given to the WTO, were sent directly to PORA analysts, then the PORA system could record the data and alleviate the paperwork burden on the WTO. The data would then be recorded in a standard fashion.

In summary the PORA system can provide a listing of raw scores, summary statistics (CEPs, etc.), and comparisons with fleet averages for each pilot in each delivery mode. These listings can be prepared within seven days of their receipt by PORA data processors, and returned to the squadron WTO.

REPORT FORMATS AND RESULTS OF THE A-7 PORA TEST

Part of this project was a five-month test of the PORA system using two A-7 squadrons, based at Cecil Field, here denoted by VA-998 and VA-999. This section discusses the results of this A-7 PORA test and shows the report formats supplied to the participating squadrons.

This section is organized to follow the operational sequence model for the A-7. We first develop the report formats having to do with sortie generation capability. Then we discuss navigation proficiency. Next, we develop the reports of weapons effectiveness. Finally, we combine all of the component capabilities to present the overall squadron measure of effectiveness: targets killed per day.

PORA Reports of Sortie Generation Capability

The Navy commander must be prepared to deal with various scenarios and contingencies. The PORA system has been

designed to provide this flexibility by generating performance estimates based on the scenarios selected by the commander.

We chose two types of flight schedules in the PORA evaluation. For each, we have the following specifications:

- The carrier conducts seven launch cycles during the flying day.
and
- The launches are at 105-minute intervals.

Under our first scenario, the A-7 squadron flies an equal number of sorties on each cycle. The sortie generation model determines the maximum sustained effort by the squadron. In the second scenario, the A-7 squadron flies only in major strikes on the first, fourth, and seventh cycles. The model determines the maximum sortie generation capability (equal number of sorties for three strikes).

The first schedule used in the readiness assessment corresponds to the small groups of aircraft that might be sent to lightly defended targets. The second schedule corresponds to large alpha strikes that might be sent into heavily defended areas. The sortie generation model allows the Navy commander to specify other types of schedules in order to match the scenario of interest. In this way PORA can produce performance estimates tailored to specific scenarios.

Table 1 summarizes the results of the sortie generation model for the two scenarios. The average availability (Mission Capable) for deployed A-7 squadrons in 1979 was 57.9%. As shown in Annex B-2, this average implies an availability of 64% at the start of the flying day. By using this 64% value as an input to the sortie generation model, we obtain a fleet average of 20.8 sorties per day for

TABLE 1: SORTIE GENERATION CAPABILITY
FOR THE TWO TEST SQUADRONS

<u>Squadron</u>	<u>Start of Day Availability</u>	<u>Total Daily Sortie Generation</u>	
		<u>Scenario #1</u>	<u>Scenario #2</u>
VA-998	67.8%	22.0	19.6
VA-999	76.6	24.9	22.2
Fleet Average	64.0	20.8	18.6

the first scenario and 18.6 sorties for the second. This lower sortie rate is not surprising because the scenario represents more of a surge effort. Both of the squadrons in the PORA test had better than average aircraft availability. Thus, they are both estimated to generate more sorties than the average fleet squadron.

Navigation Capability

An attack aircraft must navigate to the target, locate it, and identify it before the target can be destroyed. For many mission profiles, the probability of successfully completing these navigational tasks is near unity. For missions with a low altitude approach, some failures will occur in this phase of the mission. The probability is dependent on the weather and the nature of the target.

As discussed earlier in the DATA section, there is a paucity of performance data for the navigational phase of the operational sequence model. The A-20-R exercises indicate a probability of .9 for successful navigation with a low altitude profile. Because most conventional combat missions are conducted at higher altitudes than the A-20-R, a higher probability seems appropriate for the conventional mission. The present PORA system merely assigns a probability of .95 to all squadrons for this factor.

Reports on Weapons Delivery Capability

Data concerning weapons delivery proficiency start with the individual pilot. The lowest level PORA report processes each pilot's delivery accuracy data, formats the data for his inspection, and gives him fleet averages for comparison. Figures 7 and 8 are samples of such reports for two of the weapon delivery modes. The pilot and the bombing scores in these figures are real, but the identity of the

WA-999

PILOT: LTJG Q
FIRST TOUR

DELIVERY: CONVENTIONAL BOMBING --- DAY DIVE

The date the training cycle began is 12/ 8/79
The date now is 5/31/80

DAY	SCORE	STANDARD
1/15/80	18	27.22
1/29/80	18	26.30
1/30/80	24	26.23
1/30/80	30	26.23
3/11/80	23	23.82
3/19/80	15	23.39
3/20/80	10	23.34
5/28/80	60	20.16

Months of Training	Estimated CEP	Standard CEP
5 (actual months completed to date)	21.47	20.04
9 (completion of normal training)	17.77	16.81

FIGURE 7: SAMPLE PORA REPORT - DAY DIVE BOMBING

WA-999

PILOT: LUJG Q
FIRST TOUR

DELIVERY: CONVENTIONAL BOMBING -- NIGHT DIVE

The date the training cycle began is 12/ 8/79
The date NOW is 5/31/80

DAY	SCORE	STANDARD
1/29/80	15	26.30
2/26/80	5	24.60
3/12/80	40	23.76
5/ 9/80	17	20.95

Months of Training	Estimated CEP	Standard CEP
5 (actual months completed to date)	16.86	20.04
9 (completion of normal training)	14.65	16.81

FIGURE 8: SAMPLE PORA REPORT - NIGHT DIVE BOMBING

pilot has been disguised. COMLATWING ONE has requested that PORA reports sent outside of the squadron conceal the identities of individual pilots and squadrons.

Figure 7 gives the day dive-bombing scores (in meters) for one of the pilots, LTJG "Q". The report gives the date of each bomb drop, the pilot's miss distance and the "standard." The standard score is taken from the learning curve representing the average fleet performance for pilots at the corresponding point in the training cycle (see Figure 6). Then, using the mathematical method described in Appendix A, PORA calculates estimated performance and displays it at the bottom of the report.

Most of LTJG Q's miss distances are clustered around the training standard (fleetwide learning curve). The exception is his most recent bomb, which was rather inaccurate. From these data, the PORA model estimates a present (31 May 1980) CEP of 21.5 meters for him. As expected, this result is very close to the standard learning curve, which predicts a 20.0 meter CEP at this stage of the training cycle. There are four months remaining in the training cycle, and we expect that Q will continue to improve his bombing skills. The PORA system projects a CEP of 17.8 meters for Q if he continues to decrease his miss distances along a curve generally paralleling the standard learning curve. This projection compares with an ending CEP of 16.8 meters for the average fleet pilot.

At this point, we note that the "fleet average" learning curve used here is based only on the experience of a single A-7E squadron. As PORA continues, the bombing scores for many squadrons and many training cycles will accumulate, and the standard curve will almost certainly be shifted.

Figure 8 is a similar report format for night dive bombing. In this delivery mode, we find that Q is slightly better than the fleet average. We collected data for all of the weapon delivery modes previously listed in the DATA section and we provided the estimated CEPs for each pilot to the appropriate squadron. However, as learning curve data was available only for day and night dives the remaining report formats were completed only for these bombing modes.

These reports give each pilot a summary of his performance in each delivery mode and a comparison with fleet averages. The reports suggest areas for emphasis in subsequent weapons training.

Every experienced pilot has a judgmental feeling for what his CEP means. The PORA data augments that judgment by giving the pilot reports in the format of Figure 9. Here, the PORA system starts with LTJG Q's projected CEP of 17.8 meters. From this CEP, it calculates the single-pass kill probability (P_k) against representative targets. Q's kill probabilities are almost equal to the fleet standard because his CEP is only slightly larger than average. We anticipate that the list of targets will be expanded as PORA develops.

A report format for the squadron level is given in Figure 10. This report enables the squadron CO, OPS Officer, and Weapons Training Officer to compare their pilots with each other and with fleet standards. A report in this format will be available for each delivery mode. The asterisks are flags that PORA can provide to indicate cases of possible training deficiencies. The 10% and 25% thresholds may be changed, if so desired by the squadron's training officer. The information in these reports may suggest a reallocation of the squadron's training priorities between pilots and between delivery modes.

VA-999 PILOT: LTJG Q (FIRST TOUR)
 DAY DIVE

The date the training cycle began is 12/ 8/79
 The date NOW is 5/31/80

Kill Probability per Sortie for Various
 Types of Attacks against Representative Targets
 (Projected to End of Training Cycle) CEP = 17.8

TYPE OF ATTACK	TARGET TYPE	KILL PROBABILITY PER SORTIE	
		Combat Standard	LTJG Q
Conventional Bombing	Light Tank (3m radius)	.022	.020
	Heavy Tank (5m X 9m)	.031	.028
	Bridge (3m X 100m)	.042	.040
	Small Bldg. (10m X 12m)	.080	.072
	Large Bldg. (20m X 25m)	.240	.219
	Truck (in park)	.200	.199

FIGURE 9: TARGET KILL PROBABILITIES FROM
 PILOT'S PROJECTED CEP

VA-999

DAY DIVE

CONVENTIONAL BOMBING CEP SUMMARY

PILOT	TOUR	PRESENT ESTIMATE of CEP	TRAINING STANDARD	COMBAT STANDARD
	1	18.5	20.0	16.8
	2	14.6	19.5	16.5
	1	14.0	20.0	16.8
	1	14.9	20.0	16.8
	2	12.9	19.5	16.5
	2	11.4	19.5	16.5
	3	10.0	19.0	16.1
	1	* 24.4*	20.0	16.8
	1	14.1	20.0	16.8
	1	** 25.7**	20.0	16.8
	1	8.6	20.0	16.8

FIGURE 10: CEP SUMMARY

Figure 11 is a histogram of bombing CEPs for pilots in the two squadrons in the PORA test. Histograms for the other bombing modes are provided in Appendix D. This histogram rises sharply at a CEP of about 15 meters. Ballistic dispersion and other factors beyond the control of the pilot rule out the occurrence of CEPs substantially less than 10 meters. However, the distribution has a long "tail" to the right, reflecting a considerable fraction of pilots with CEPs of 20 to 32 meters.

The full distribution of scores among pilots provides more information than a simple average score as a basis for comparison. A pilot can then rank his performance against that of his peers on a pilot-to-pilot comparison. Similar histograms, accumulated over all squadrons and over several training cycles, will be provided as a by-product in any future PORA work.

The PORA system also produces inter-squadron comparisons as shown in Table 2. The results here suggest that VA-998 may have a problem, because its CEPs are about twice those of VA-999. Table 2 does not, however, identify the cause of VA-998's larger bombing scores. The squadron and wing commanders should examine other information at their disposal to determine the reason. Potential causes might be:

- A disparity in the general pilot experience level between the two squadrons,
- Insufficient training in VA-998,
- Older aircraft in VA-998, or
- Better bombing system maintenance procedures in VA-999.

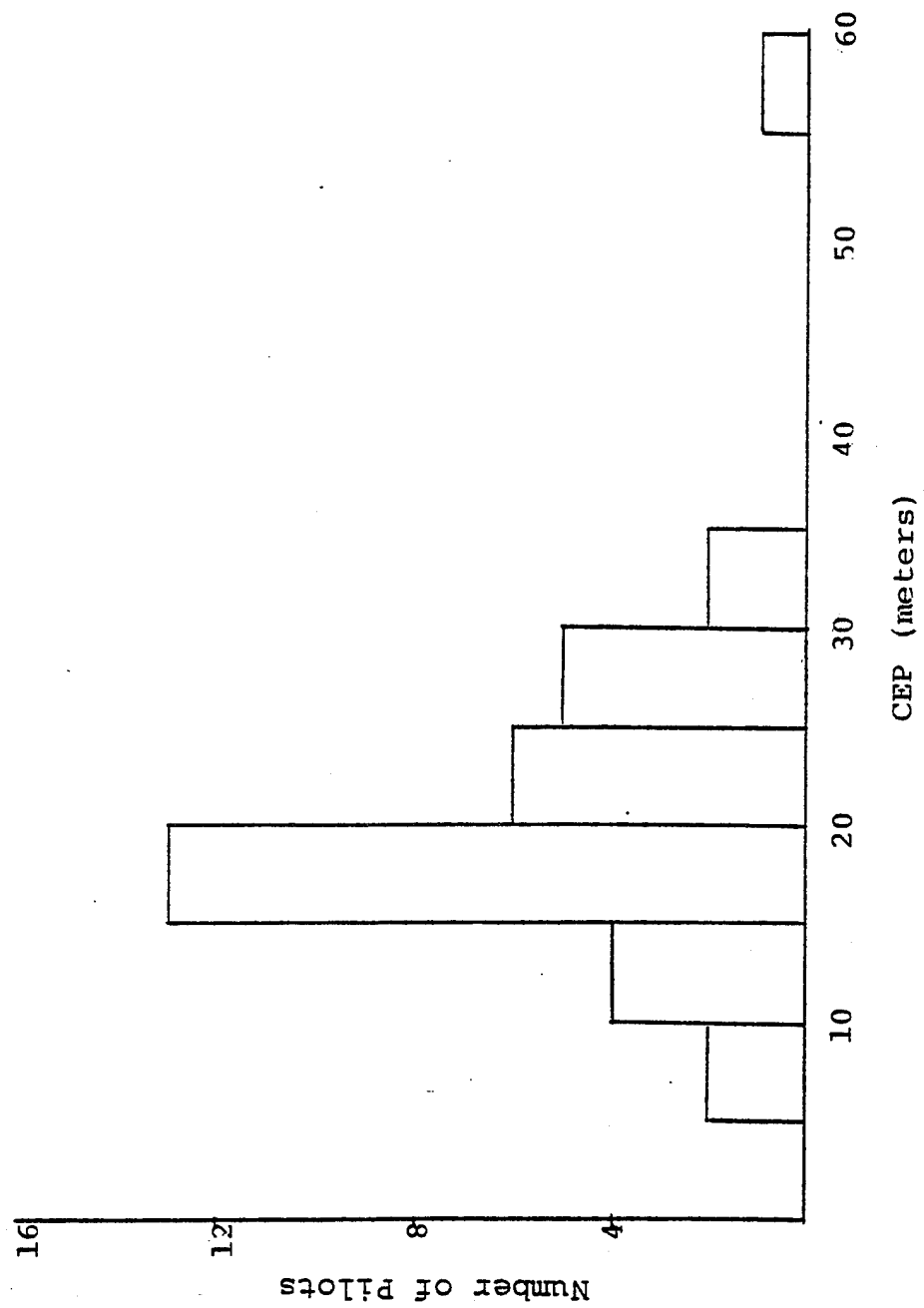


FIGURE 11 : DAY DIVE BOMBING PERFORMANCE DISTRIBUTION

TABLE 2: AVERAGE SQUADRON CEPs
(Meters)

<u>Squadron</u>	<u>Day Dive</u>	<u>Lay Down</u>	<u>Minimum Altitude</u>	<u>Night Dive</u>	<u>Radar</u>	<u>Rocket</u>	<u>Roll Ahead</u>	Over-the-		
								<u>Loft</u>	<u>Shoulder</u>	<u>Pop-up</u>
VA-999	15.78	20.16	8.73	17.72	61.89	15.08	10.85	72.07	152.21	---
VA-998	24.51	43.85	18.19	32.18	256.88	---	---	117.42	333.48	22.66
AVERAGE	20.01	32.01	13.46	25.18	155.78	15.08	10.85	94.74	260.57	22.66

Figures 12 and 13 illustrate another type of report produced in the PORA. This report examines the effect of pilot experience on delivery accuracy. Intuitively, we expect the average third-tour pilot to bomb more accurately than the average first-tour pilot. However, these PORA results indicate that pilot experience is not a major factor in weapon delivery accuracy. Here, we see some improvement in day dive-bombing accuracy as pilots get more experienced. Depending on the squadron, there is an improvement in night-bombing accuracy for the more experienced pilots. But the differences are not great. This type of information is useful in predicting the performance of pilots when we have little or no data (e.g., a pilot recently arrived or expected soon).

We have examined the time trends in the bombing scores of the two squadrons during the test period using linear regression techniques. The VA-999 pilots showed an average decrease of 2.9% per drop early in the training cycle. The rate of decrease later diminished, in agreement with the behavior noted in Figure 6 for another squadron. The data for VA-998, on the other hand, show no clearcut learning curve. A refinement of the "fleet average" learning curve in Figure 6 will have to await the accumulation of additional data over a longer time period and a wider sample of squadrons.

Now we turn to PORA reports that aggregate the capabilities of an entire squadron, i.e., reports of interest to the squadron's CO and to higher levels of command. Navy commanders need to assess performance under a variety of operational situations and scenarios. The targets in various scenarios may differ considerably. That is, the types of targets encountered in a NATO war may be quite different

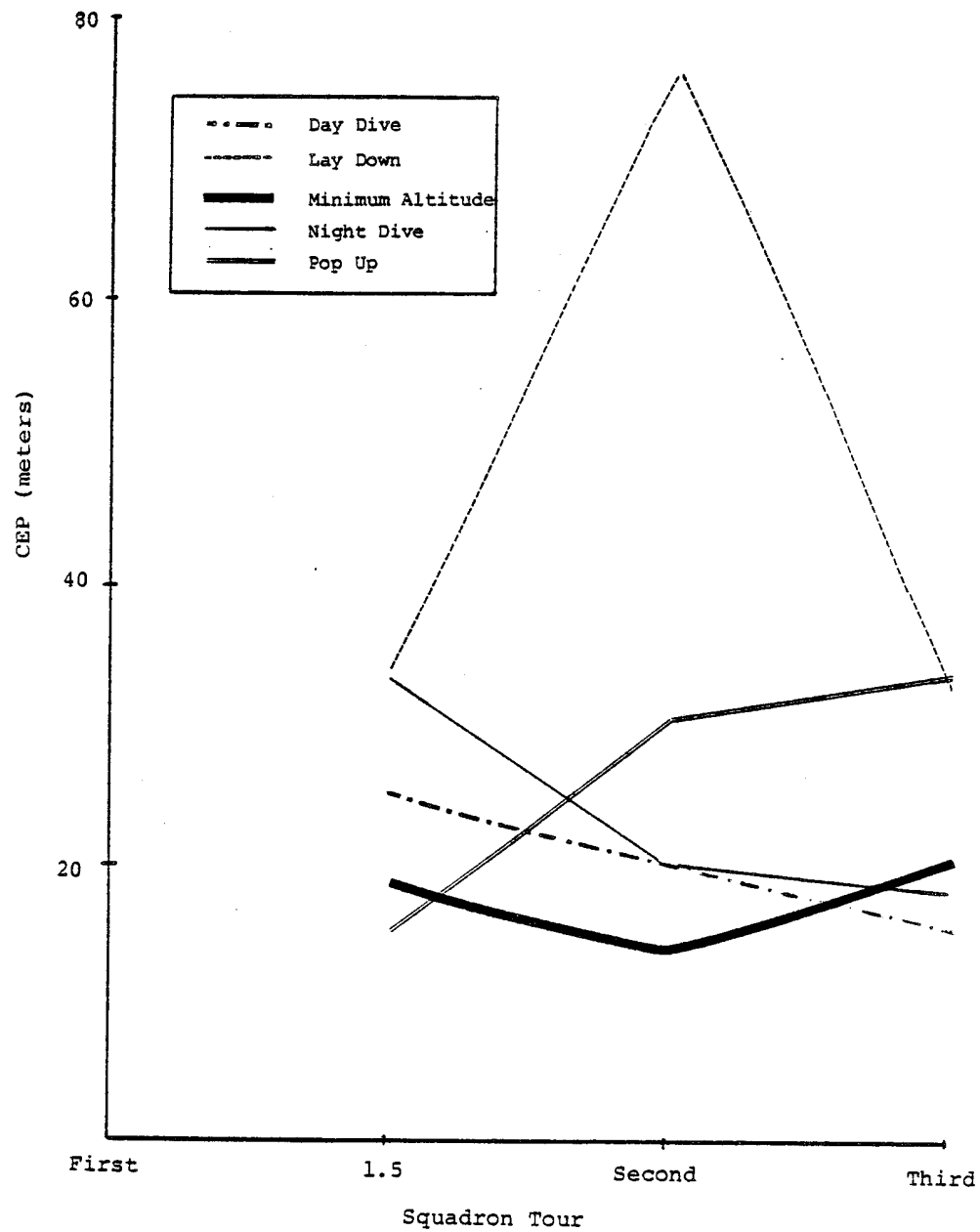


FIGURE 12: IMPACT OF PILOT EXPERIENCE ON BOMBING ACCURACY (VA-998)

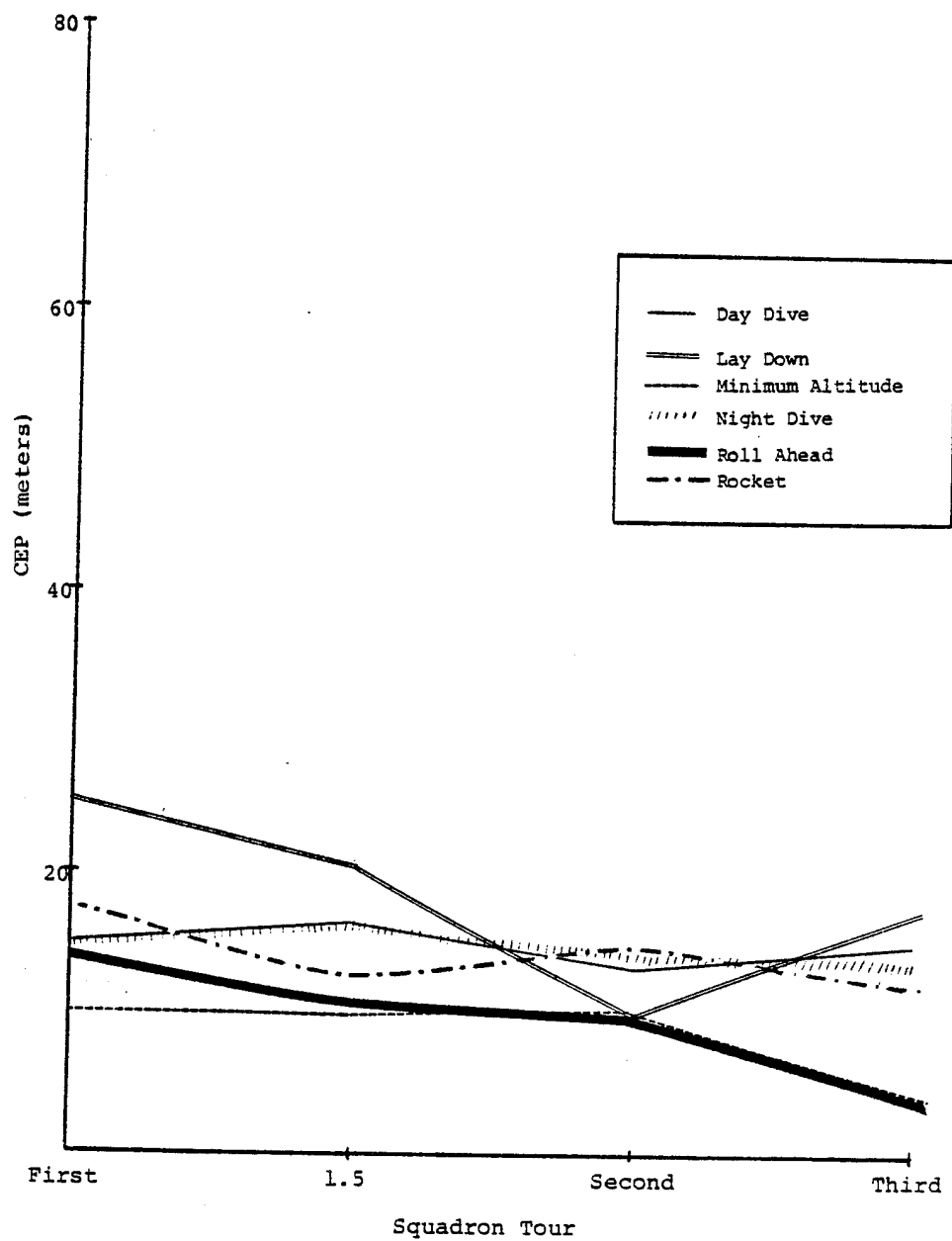


FIGURE 13: IMPACT OF PILOT EXPERIENCE ON BOMBING ACCURACY (VA-999)

from those in a Middle Eastern war, one in the Caribbean, or an encounter at sea with the Soviet Navy. The PORA system presents several "target mixes" and the commander can choose the mix that most closely resembles the targets in the scenario of interest. Then, the PORA reports provide measures of performance against that target mix.

Figure 14 gives the expected number of sorties for VA-999 to destroy various target mixes using the day dive bombing mode. These mixes are described in detail in Annex A-3. In general, target Mix A contains more smaller (and harder to hit) targets than the other two mixes. Target Mix C contains more large area targets.

In Figure 14, the columns headed "Now" indicate the results based on the CEPs for VA-999 pilots shown in Figure 10. These are the present PORA estimates of delivery accuracy. For Mix A (without Walleye), VA-999 should expect to destroy the targets with bombs in about 158 sorties, if the squadron were to enter combat at this time. However, by the end of the training cycle, we expect the pilots to have improved their delivery accuracy in accordance with the learning curve. Thus, the PORA system estimates that only 142 sorties will be required to destroy the target mix by the normal deployment date. The squadron's performance can similarly be projected to other dates in case the commander is contemplating an early deployment to meet a contingency.

In Figure 14 the columns headed "Combat Standard" reflect the performance of a hypothetical squadron consisting entirely of average pilots (each one has CEPs precisely on the end point of the standard learning curve). Such a squadron would require 202 sorties, on the average, to destroy target Mix A. VA-999 requires fewer sorties to destroy the same targets. This result should be expected,

VA-999

Expected Number of Sorties Required
to Kill Various Target Mixes -- DAY DIVE

The date the training cycle began is 12/ 8/79
The date HMM is 5/31/80

	WITH MALLEVE			WITHOUT MALLEVE		
	Combat Standard	Projected	Now	Combat Standard	Projected	Now
MIX A	132.5	89.0	99.4	202.3	141.9	158.4
MIX B	191.2	138.7	151.8	215.4	156.9	172.1
MIX C	161.0	122.1	132.0	161.0	122.1	132.0

FIGURE 14: SQUADRON CAPABILITIES AGAINST
REPRESENTATIVE TARGET MIXES

because the VA-999 pilots are generally more accurate than the fleet standard (Figure 9). It should be noted that the commander can, if desired, specify a combat standard different from the fleetwide average to assess performance.

It is clear that "smart bombs" such as Walleye or laser-guided weapons will be used in combat and will reduce the number of sorties required to kill a given target mix. Unfortunately, the fleet gets little opportunity to train with these expensive weapons, and without this data on training performance the PORA system cannot be truly "performance-oriented" with regard to these weapons. We are unable to develop performance estimates for individual pilots or even squadrons and are limited to the use of fleetwide averages in estimating their effectiveness. Indeed, the fleetwide average performance may be based on only a few weapons per year.

Figure 14 illustrates a PORA report including the performance of a "smart bomb". If the commander feels that Walleye weapons will be available, and that visibility conditions will be appropriate, then he consults the "with Walleye" portion of the report. Otherwise, he consults the "without Walleye" portion. Here, as expected, we see that the use of Walleye cuts down the expected number of sorties to destroy Mixes A and B. However, the results for Mix C are unaffected, because it has no targets suitable for Walleye.

In this limited pilot PORA effort, the weaponeering was done assuming only one bomb was dropped during a pass--i.e., similar to training runs, in order to meet the time deadline for the study. Clearly in combat, a string of bombs could be dropped with correspondingly higher kill probabilities -- a lower number of sorties per target kill. Insertion of

bomb strings into the weaponeering calculation will be accomplished in follow-on work. Meanwhile, the results given here are obviously understating the attack effectiveness but are accurate for relative comparison between squadrons.

PORA Reports of Total Kill Capability per Day

The preceding sections discussed PORA estimates of sortie generation capability, navigational proficiency, and weapons delivery accuracy. The PORA system combines these components to form its principal measure of performance for the A-7 squadron : the total number of targets killed per day.

Figure 15 shows the PORA report for this MOP. The column showing sortie generation is derived from Scenario #2 in Table 1. This scenario specifies three large strikes each day. Table 1 indicated that VA-999 can produce an average of 22.2 sortie per day in this scenario. The scenario also specifies that VA-999 must provide two sorties for either flak suppression or SAM suppression for each of the strikes. This leaves 16.2 sorties to attack the assigned targets in Mix A. The third column shows the .95 probability of accurate navigation and target location and identification. The next column indicates that VA-999 is expected to use 142 sorties to destroy target Mix A without Walleye (see Figure 14). The final column combines these components and estimates that VA-999 can destroy 11% of target Mix A in a day. VA-999 has both a better than average sortie generation capability and better than average bombing accuracy. These two effects combine to give the squadron almost twice the daily target-killing capability of the "fleet average" squadron. VA-998 has a slightly better than average sortie generation capability. However, its weapons delivery performance is below

FIGURE 15: FRACTION OF TARGET MIX KILLED PER DAY
(Scenario #2, Target Mix A, Without WALLEYE)

<u>Squadron</u>	<u>Strikie Sorties Flown</u>		<u>Probability of Successful Navigation</u>		<u>Expected # of Sorties To Destroy Mix A</u>		<u>Fraction of Target Mix A Killed per Day</u>
VA-998	13.6	x	.95	÷	298.0	=	.043
VA-999	16.2	x	.95	÷	141.9	=	.108
Fleet Average	12.6	x	.95	÷	202.3	=	.059

average. The combined result is a below average (.043 vs .059) daily target killing capability.

Figure 16 is a similar PORA report for Scenario #1, Target Mix C. Here, the sortie generation is greater for both squadrons, and no sorties are required for defense suppression; the numbers in the sortie column are taken directly from Table 1. The targets in Mix C tend to be larger and easier to hit than the targets in Mix A. The superior weapons delivery accuracy for VA-999 gives it an advantage in the expected number of sorties column. However, the advantage is not as great for Mix C as for the more demanding targets in Mix A.

PORA reports in formats like Figures 15 and 16 are useful at the squadron level and at higher levels of command. At the squadron and wing levels, such reports can suggest areas needing most attention. In the cases presented, both squadrons are seen to be above average in aircraft availability and sortie generation. However, a redirection of resources to improve VA-998's weapons delivery accuracy appears to be desirable.

At higher levels of command, reports in this format provide an estimate of the fleet's performance in projected combat scenarios. For example, the carrier air wing containing our two A-7 squadrons might be under consideration for a deployment. If the deployment were likely to result in a situation like Scenario #1, the wing could be expected to destroy .287 (.093 + .194) target complexes like Mix C every day (not including the contribution of A-6 aircraft). These composite results for VA-998 and VA-999 may be compared with the .246 (2 X .123) target complexes that would be destroyed by two average A-7 squadrons.

FIGURE 16: FRACTION OF TARGET MIX KILLED PER DAY
(Scenario #1, Target Mix C)

<u>Squadron</u>	<u>Attack Sorties Flown per Day</u>		<u>Probability of Successful Navigation</u>		<u>Expected # of Sorties to Destroy Mix C</u>	<u>Fraction of Target Mix C Destroyed per Day</u>
VA-998	22.0	x	.95	÷	225.0	= .093
VA-999	24.9	x	.95	÷	122.1	= .194
Fleet						
Average	20.8	x	.95	÷	161.0	= .123

Alternatively, the commander may specify absolute combat standards for the PORA. For example, he may declare a requirement to destroy the target complex within two days. This requirement implies that .5 target complexes per day be destroyed. However, this wing can only destroy .287 target mixes per day. Thus, the commander will conclude that two carrier air wings are needed to meet the military requirement. On the other hand, the commander may lessen the requirement to destroy the targets in four days, (i.e., .25 target mixes killed per day). The commander will see that the A-7 squadrons examined in Figure 13 can do that job without additional help.

F-14 PORA

MISSIONS

The F-14 aircraft provides the fighter component for about half of the Navy's carrier airwings. It is gradually being phased in to replace F-4 aircraft in other airwings.

The four main weapons of the F-14 are:

- long-range Phoenix missile (AIM-54A),
- medium-range Sparrow missile (AIM-7F),
- short-range Sidewinder missile (AIM-9L),
and
- MK-61A1 gun.

The F-14 also has a limited capability to deliver air-to-ground weapons.

COMNAVAIRLANT's Air Wing Readiness Training Manual lists the primary mission areas for the F-14 with the following weights:

AAW:	Anti-Air Warfare	50%
ASU:	Anti-Surface Ship Warfare	5%
STW:	Strike Warfare	10%
CCC:	Command, Control and Communications	5%
MOB:	Mobility	30%

One of these missions, AAW, carries half of the total weight. The MOB "mission", carrying a weight of 30%, does not compete with the other missions as it is required for all missions. Thus, analysis of AAW really requires

examining 80% of the mission weight. The missions of ASU, STW and CCC are secondary missions for the F-14, carrying 20% of the weight assigned in COMNAVAIRLANT's Manual. They are not addressed in this pilot study.

The AAW area can be broken into two basic missions: force defense and strike escort. Accordingly, the principal measures of performance in this report reflect the F-14's capability to fly against and destroy enemy bombers and fighters in these missions, respectively.

OPERATIONAL SEQUENCE MODELS FOR THE F-14

Figure 17 shows a simplified operational sequence for the two primary missions of the F-14. For both of these missions, the first requirement is to produce sorties by aircraft at an appropriate level of availability. This is in common with the first requirement for A-7 missions, i.e. sortie generation, and the same sortie generation model is used for the two aircraft.

The remaining portions of the F-14 missions differ from the A-7 mission. In the first F-14 mission, force defense, the sortie generation results must be combined with the intercept performance to produce an estimate of the number of incoming bombers or missiles shot down by F-14s. In the second mission, protection of strike aircraft, the F-14's performance in ACM must be considered. The PORA system combines the sortie generation and ACM performance to estimate the number of enemy interceptors shot down, and the number penetrating to the attack aircraft.

Both of these performance estimates require that a standard operational situation be specified to complete the calculations. These operational situations are discussed in the following.

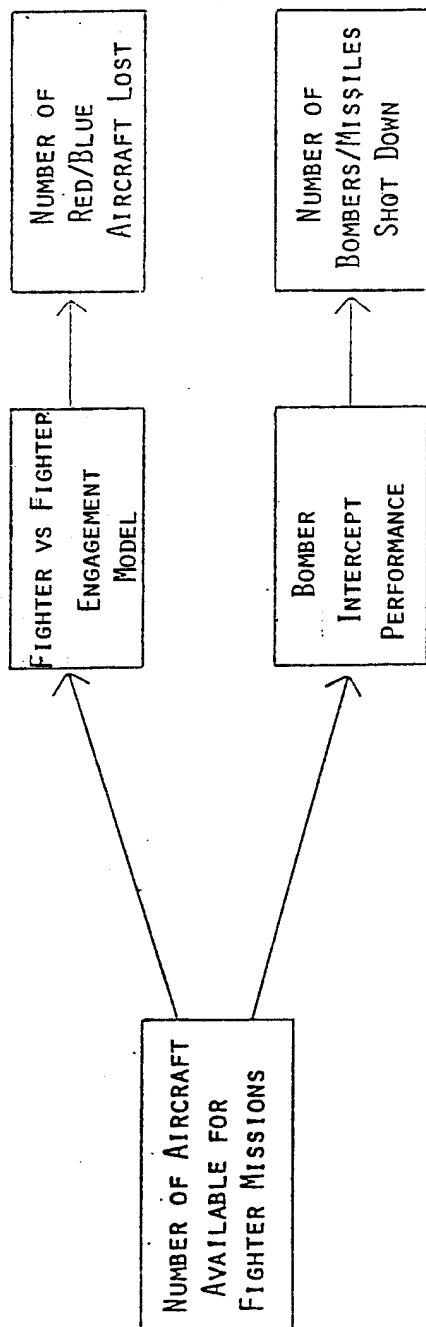


FIGURE 17: OPERATIONAL SEQUENCE MODEL

MEASURES OF PERFORMANCE FOR THE F-14

This section presents tentative measures of performance (MOPs) for the F-14 PORA. A limited amount of performance data was collected for the F-14. However, there was no F-14 PORA test comparable to the several month test of PORA with two A-7 squadrons. Thus, the F-14 MOPs are subject to refinement when an F-14 PORA test is conducted. At that time, the inputs of Ketron's PORA analysts, officers in the test squadrons, and the functional wing staff will undoubtedly dictate some modifications of the F-14 PORA models and report formats.

Principal MOPs for the F-14

The principal MOP for the F-14 in the force defense role is the number of enemy bombers or missiles shot down before they can attack the force.

The principal MOPs for the F-14 in the escort role are:

- the number of interceptors shot down by the escort fighters and
- the number of escort fighters lost to interceptor aircraft.

Subsidiary Measures of Performance

In addition to the principal MOPs described above, PORA produces other measures of interest. Some of these subsidiary measures are components of the principal MOPs, while others are supplementary.

MOPs for Individual Aircrews

The MOPs for individual aircrews encompass only a component of the principal measures for a total squadron (for example, the F-14 aircrew is not responsible for providing a

mission capable aircraft). The MOPs for aircrews include:

- the probability of conducting an unassisted intercept,
- the probability of conducting an intercept with vectoring information from a third party (E-2, ship, or shore-based radar),
- the expected number of enemy aircraft killed in an encounter,
- the expected number of F-14 losses in an encounter, and
- the probability of a successful missile firing against bombers.

The PORA approach generates these types of measures for each aircrew, and compares its performance with average fleet performance. These measures and comparisons provide the aircrew with an assessment of its performance in various components of the total F-14 mission. They also suggest areas of emphasis for the aircrew's subsequent training.

MOPs for the Squadron Commanding Officer

The CO of a squadron receives all of the individual aircrew performance measures. These measures, and their comparison to the fleet norms or absolute standards, will indicate where the squadron should place emphasis in future training.

Additionally, the PORA system provides the same MOPs aggregated over all of a squadron's aircrews to the CO. These squadron-level MOPs are presented with the corresponding averages for all fleet squadrons. The CO can thus evaluate his squadron against fleet norms.

As mentioned previously, the squadron performance includes more than the performance of aircrews. The squadron

is responsible for generating sorties with aircraft at an appropriate level of availability. Thus, the squadron's daily sortie generation capability is another MOP provided to the CO. The PORA sortie generation model provides this MOP for any desired set of missions and flight schedule.

The principal MOPs at the squadron level combine the sortie generation and ACM or intercept MOPs to estimate the total number of enemy bombers or interceptors shot down by the squadron (in specified situations or scenarios).

Measures for the Wing and Higher Levels

At higher levels of command, there is less interest in the performance of individual aircrews and more interest in the performance of squadrons and air wings.

The PORA system provides the previously described MOPs of overall squadron performance to the air wing commander. He will also receive these MOPs aggregated for the two fighter squadrons within his wing and a comparison with the average performance of F-14s in other air wings.

DATA SOURCES FOR F-14 PORA

There are data available on various facets of F-14 performance but the quality and quantity varies greatly. These data are found in periodic reports submitted by the squadron and in exercise reports. Aircraft availability data is available in the SCIR system in essentially the same degree of completeness as for the A-7. However, performance data for tactical engagements and weapon delivery are not as plentiful as A-7 weapon delivery data. Air-to-air missiles and their exercise targets are far more expensive than the practice bombs used by attack aircraft and the data on weapons effectiveness of the F-14 are correspondingly scarce. The TACTS provides good data on air combat maneuvering (ACM)

capabilities but the data rate for any one aircrew is very small and not continuously collected.

Data For Estimating Sortie Generation Capability

The F-14 PORA uses the same sortie generation model as does the A-7 PORA. Therefore, the sources of supporting data are nearly identical. The SCIR system provides data on aircraft availability while the cumulative probability-of-repair statistics are taken from the Sixth and Seventh Fleet data described in the discussion of A-7 PORA.

The SCIR system provides data on the average number of aircraft possessed by each squadron. It will also provide the squadron's availability rates for the following levels of readiness (OPNAVINST 5442.4F):

- A - Optimum Performance Capability
- B - Composite Force Air Superiority
- C - Escort/Strike
- D - Expanded ACM Weapons
- E - ACM Weapons
- F - Conventional Air-Surface (Computer)
- G - Conventional Air-Surface (Pilot)
- X - IMC Flyable
- Y - Safely Flyable
- Z - Not Safely Flyable

The full mission capable category comprises levels A and B. Levels C through G provide mission capability at increasingly degraded degrees. When the SCIR system starts to report availability in these finer levels, the sortie generation model will relate the levels of mission requirements and calculate multimission sortie generation capability.

Ketron examined a small sample of F-14 availability

data, as summarized in Table 3. At the time these data were generated, there were shortages of spare parts for the F-14. Accordingly, spares were not allocated to all squadrons and the availability statistics do not necessarily reflect the capabilities of the various squadrons to maintain their aircraft. VF-14 and VF-32 were in the latter part of their training cycle, preparing for a deployment. These squadrons were given a high priority for spare parts, and their availability rates were the highest in the fleet. VF-142 and VF-143 had just returned from a deployment and were early in their training cycle. They had low priority for spare parts. As a result, their availability rates were the lowest in the fleet. VF-41 and VF-84 were deployed in the Indian Ocean. Due to their deployed status, they received high priority; however, their remote location precluded rapid delivery of spare parts. Thus, these two squadrons had intermediate availability rates. For these data, it is clear that projections of the sortie generation capability of squadrons are dependent on their position in the training cycle and that this factor must be explicitly incorporated in any inter-squadron comparison. This, however, was not done with the F-14 data in this initial project.

Data on Intercept Performance

Data concerning the skill of aircrews in conducting intercepts are sparse. We were unable to find any source of routinely recorded intercept data. There are occasional reconstructed exercises that provide pertinent data such as the SeaBat series. However, we cannot expect to find intercept exercise results for a squadron frequently enough to monitor an aircrew's or squadron's progress through a turnaround training cycle.

TABLE 3: F-14 AVAILABILITY

	Mission	Fully Mission	
	<u>Capable</u>	<u>Capable</u>	<u>STATUS</u>
VF-14/32	61.2%	43.4%	JUST PRIOR TO DEPLOYMENT
VF-41/84	45.9	36.7	INDIAN OCEAN
VF-142/143	33.5	19.2	EARLY IN TRAINING CYCLE

Ketron analysts discussed this problem with officers in RVAW-120, the E-2 training squadron. The consensus was that any data recording aboard an E-2 directing an intercept could degrade the E-2's performance in the intercept. Some data is recorded by the E-2 crew after the flight i.e., some hours after the actual event. Thus, the available data may lack detail and accuracy. The E-2 officers also felt that, questions of detail and accuracy aside, this data would have to be combined with data from the interceptor and the target to give the estimates that PORA needs. Hence, a small reconstruction effort would be required for each data point on intercept performance during routine training operations.

In the more formal (and reconstructed) SeaBat exercises, fighter aircraft fly missions in the force defense role in an EW environment. They are vectored by ships, E2-Cs, and E3-As to intercept incoming bombers that attempt to penetrate and attack a (simulated) battle group. The bombers are supported by electronic jamming aircraft. In the early portion of the exercise, the fighters are urged to "experience the EW" and let their system be defeated. Later, they try to counteract the jamming.

The SeaBat exercise requires special reporting by the fighters, the interceptors, and the unit (aircraft, ship, or land-based radar site) providing vector information to the fighters for use in the exercise reconstruction and analysis effort. The SeaBat exercise final reports present some summary performance statistics by squadrons in the form of successful intercepts and total intercepts attempted. These performance data are useful in estimating F-14 performance in a reasonably realistic jamming environment.

Unfortunately, fighter squadrons participate in SeaBat exercises infrequently, and the data is necessarily

limited. In addition, the exercise reports contain no performance data for individual aircrews or squadrons. Any application of F-14 PORA will have to retrieve data on individual aircrews and squadron performance.

The FOX ONE data base comes closest to satisfying PORA's requirements for intercept data (given the launch of a suitably available aircraft). COMNAVAIRLANT requires a report by any squadron that conducts, or even attempts, a live missile firing. Once the aircraft has taken off with "wheels in the well," the squadron is charged with a firing opportunity. Each opportunity is graded as a success, failure or, (in rare cases), a no-test. A no-test assessment is made only when the result was beyond the control of the F-14 squadron: if the target drone was shot down by another fighter, or if the range safety officer cancels the firing attempt. Failures are assessed for air aborts before the interceptor reaches the target, for failure to reach a firing position, for failure of the missile to launch, and for failure of the missile to hit (or come within a specified distance of) the target. Annex C-2 describes how performance estimates are derived from FOX ONE.

The FOX ONE data, therefore, reflect almost everything that a squadron must do in an intercept. However, the vector portion of the intercept is probably less demanding of the air crew than a typical combat intercept, as the majority of the drones are slower than the anticipated bomber speeds. However, for this report, we have used the FOX ONE data as the indicator of squadron performance in the intercept mission. Again the data is too sparse to assess air crew performance. We hope to augment these data from additional sources as the F-14 PORA develops.

Data for Estimating ACM Performance

The Tactical Air Crew Training System (TACTS), formerly the Air Combat Maneuvering Range (ACMR), is a rich source of data for aircrew proficiency in ACM. Every fighter squadron has 2-to-3-week training exercises at the TACTS during its turnaround period.

The adversary squadron for the TACTS is VF-43. This squadron is trained in enemy tactics, and its pilots are very experienced. VF-43 is employed full time at the TACTS, and it provides tough and realistic opposition for the fleet squadron in its training exercises.

The fleet pilots are put through a sequence of encounters that generally increase in complexity throughout the exercise period. These start with one F-14 aircraft against one VF-43 aircraft (1 v 1) encounters. The progression is normally to 2 v 1, 2 v 2, 4 v 2, and sometimes more complicated engagements.

The TACTS records with great accuracy the position and velocity of all aircraft and (simulated) weapons fired during the exercise. The TACTS computer system and VF-43's evaluation provide a reconstruction and scores for the fleet pilots. These scores are the principal source data for PORA estimates of ACM performance by pilots and squadrons.

Learning Effects

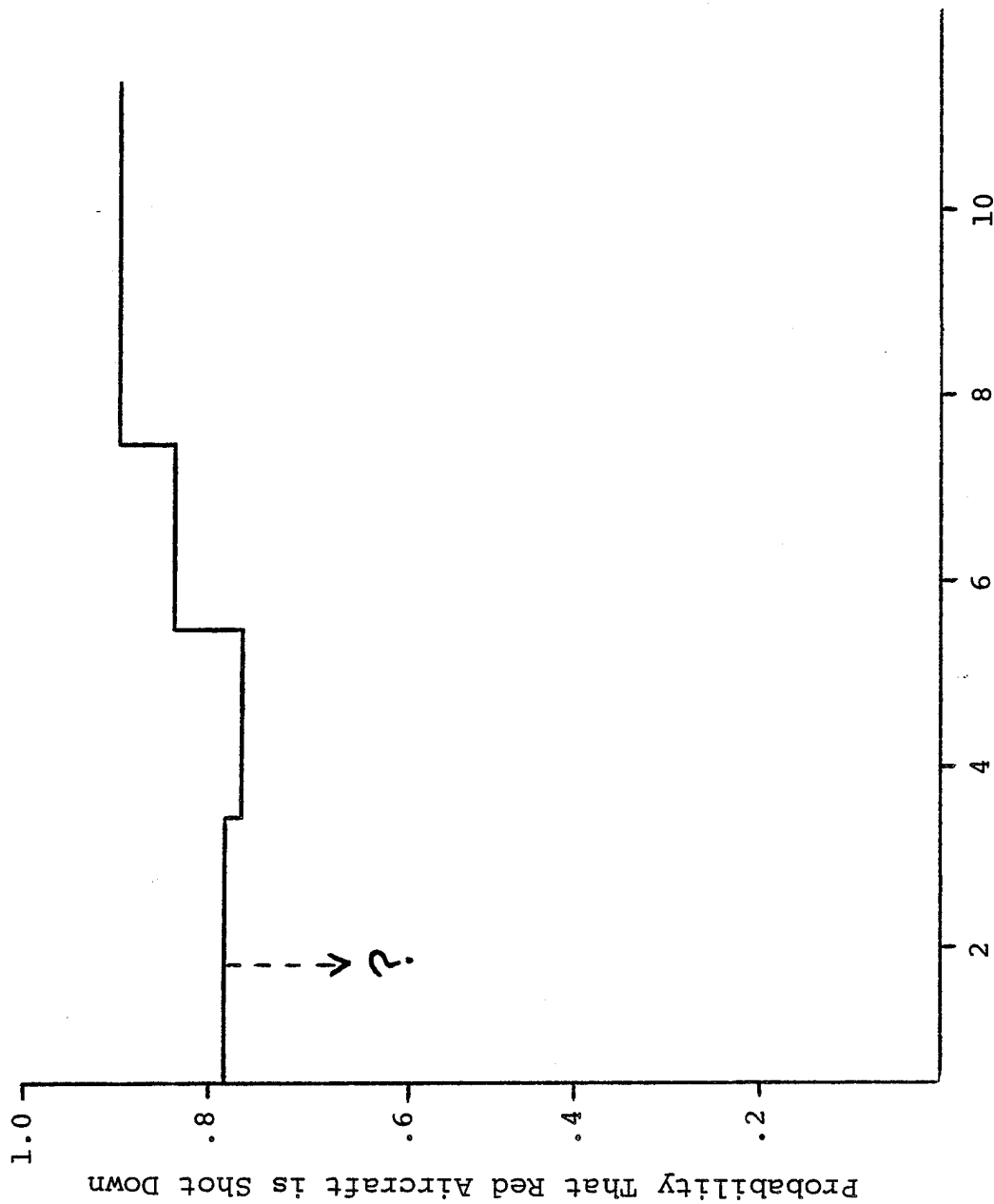
All of the aircraft on the TACTS range are tracked with great accuracy, and a computer reconstruction is available immediately after every sortie. The adversary pilots from VF-43 also provide a critique of each encounter. Thus, the TACTS gives fighter aircrews experience in ACM plus immediate and accurate feedback. We have examined some of the

scores from TACTS exercise in an attempt to measure learning by the F-14 aircrews.

Figure 18 shows a trend in the proficiency of F-14 (Blue) aircrews as they progress through a TACTS exercise. The horizontal axis indicates the number of encounters that the aircrew has experienced in its exercise (at any odds). The vertical axis shows the probability that the Blue aircrew (or its wingmen) shot down the adversary (Red) aircraft in the encounter. The data in this Figure are only for encounters at 2 v 1 odds. The Blue crews shoot down the Red aircraft with probability .76 early in the exercise (on the fourth or fifth encounter of the exercise). This probability rises to .89 later in the exercise (after eight or more encounters). The observed success rate of .78 in the first two encounters is not an accurate reflection of aircrews' capabilities early in the exercise. The Red pilots usually restrict their maneuvers in the first few encounters. The restrictions are to give the Blue aircrews an easier ACM problem at the beginning of the exercise and help the learning process. Thus, as indicated by the downward arrow, the graph in Figure 18 understates the degree of learning by the Blue aircrews.

One would also expect aircrews to fare better in their second TACTS exercise. We have data from one squadron that tends to confirm this learning effect. The squadron had its first TACTS exercise in 1978. It had another exercise in 1979. In the second exercise, the squadron had seven crews that had also participated in the first. The squadron also had seven crews that had not previously had a TACTS exercise.

Table 4 shows that the more experienced crews had a slightly higher success rate (.85 vs .83) than the less



Cumulative Number of Encounters for Blue Pilots
(Based on 5 TACTS Exercises)

FIGURE 18: 2 v 1 ENCOUNTERS WITH AIM-9L

TABLE 4: EFFECT OF TACTS TRAINING IN 2 v 1 ENCOUNTERS

	Aircraft Lost		
	<u>Per Encounter</u>		Exchange
	<u>Red</u>	<u>Blue</u>	<u>Ratio</u>
7 Blue Crews in First TACTS Exercise	.83	.12	7
7 Blue Crews in Second TACTS Exercise	.85	.05	17

experienced crews in shooting the Red aircraft. The experienced Blue crews were also more adept defensively, with losses of only .05 per encounter compared to .12 losses per encounter for the less experienced crews.

As more data accumulates, the PORA system can provide learning curves from historical performance data. These curves will provide fleet averages for estimating and projecting the performance of individual pilots and squadrons.

REPORT FORMATS FOR F-14 PORA

The PORA reports for the F-14 will be similar in format but different in detail from the A-7 report format. The reports of sortie generation capability will be virtually identical to the A-7 reports but obviously the aircrew reports will differ.

Navy commanders must be concerned with performance in various combat scenarios. In order that the commander be permitted to select the scenario(s) of high current interest, PORA is flexible in its inputs. For example, the commander may select a flight schedule of his choice, and a prioritized set of missions.

Table 5 gives an example for one such selection for a strike scenario. Here, we assume that there is an enemy air threat to the battle group, which is sending attack aircraft to strike targets ashore. Thus, the commander specifies that each fighter squadron's first priority is to provide two FORCECAP sorties on each of the seven daily launch cycles. In order to obtain full benefit of the F-14's missile systems, these FORCECAP sorties are to be full mission capable (FMC) aircraft if possible. If insufficient FMC aircraft are available, then the squadron is to provide mission capable (MC) aircraft to ensure the two FORCECAP

TABLE 5: ILLUSTRATIVE DAILY SORTIE GENERATION CAPABILITY
FOR F-14s FLYING FORCECAP AND ESCORT MISSIONS

<u>Squadron</u>	<u>Availability</u>		<u>FORCECAP</u> <u>Sorties Flown</u>		<u>Escort</u> <u>Sorties Flown</u>	<u>Total</u> <u>Sorties</u>
	<u>MC</u>	<u>FMC</u>	<u>MC</u>	<u>FMC</u>	<u>(MC or FMC)</u>	<u>Flown</u>
VF-1	.60	.38	1.39	12.61	5.91	19.91
VF-2	.54	.27	5.04	8.96	3.92	17.92
VF-3	.61	.42	0.07	13.93	6.24	20.24
VF-4	.62	.36	2.06	11.94	6.56	20.56
VF-5	.63	.39	1.06	12.94	6.90	20.90
VF-6	.55	.41	0.40	13.60	4.25	18.25
VF-7	.63	.46	—	14.00	6.90	20.90
VF-8	.62	.51	—	14.00	6.56	20.56
Fleet Average	.60	.40	0.73	13.27	5.91	19.91

NOTE: The MC and FMC availability factors are for hypothetical squadrons. The first priority for each squadron is to provide two FORCECAP sorties for each of seven launch cycles. The sorties are to be flown by FMC aircraft, if possible. After providing the FORCECAP sorties, the next priority is to provide the maximum number of sorties to escort attack aircraft on strike missions (FMC not required).

sorties for each cycle. After the FORCECAP requirement has been met, the squadron is to use its residual sortie generation capability to provide the maximum number of escort sortie for the strike aircraft groups. MC aircraft are adequate for this mission.

PORA Reports of Sortie Generation Capability

Table 5 gives the results of this scenario for eight squadrons and their (hypothetical) availability factors for MC and FMC aircraft. VF-2 has a MC availability factor of .54. The sortie generation model calculates that the squadron can sustain 2.56 sorties for each of the seven cycles with this availability. This gives an expected daily total of 17.92 sorties. The model estimates a daily output of 8.96 sorties from the FMC availability factor of .27. All of these will be used as FORCECAP. An additional 5.04 MC sortie must be added to meet the FORCECAP daily requirement of 14 sorties. Thus, there are 3.92 sorties remaining to be used as strike escorts. The table summarizes similar calculations for the other squadrons and for the fleet average. Only two of the squadrons are able to meet their FORCECAP requirement entirely with FMC aircraft.

This type of report allows individual squadrons to compare their sortie generation capabilities with the fleet average. It also allows the wings to compare the relative performance of their squadrons. For example, the wing commander will certainly note that VF-2 is the weakest squadron in sortie generation. Although VF-2 can fly two FORCECAP sorties per cycle, it flies fewer FMC sorties than any other squadron. Additionally, VF-2 provides fewer escort sorties than any other squadron. The wing commander will respond by taking measures to improve VF-2's aircraft availability factors.

The sortie generation statistics in Table 5 will be used in the two succeeding sections, where the squadrons' overall effectiveness in force defense and strike escort are discussed.

The Navy commander may specify alternative scenarios with different schedules and different mission priorities as described. The commander may also answer "what if" questions by changing some of the inputs (increase or decrease the availability factors, the number of aircraft assigned, etc.).

Reports for the Force Defense Role

We have missile firing success rates by squadron from the FOX ONE data base. However, the statistics in FOX ONE are classified, so we use contrived data to permit publication of this report as an unclassified document.

The PORA system generates a report in the format of Table 6. This report reflects the capabilities of the aircrews to conduct an intercept and fire a successful weapon (once the squadron has generated a sortie with an aircraft at the appropriate level of readiness for the weapon). This report allows each squadron to compare its missile-shooting performance with fleet standards. This type of report also enables the wing commanders to compare the performance of their squadrons to each other and to fleet averages.

At higher levels of the Navy, a more complete assessment of force defense is needed. Therefore, the PORA system combines the subsidiary measures of sortie generation capability with the missile firing proficiency. These produce the principal measure of performance: the number of enemy bombers/missiles that can be shot down by an F-14 squadron or by a carrier wing.

TABLE 6: PROBABILITY OF SHOOTING DOWN TARGET
GIVEN "WHEELS IN THE WELL"

<u>Squadron</u>	<u>Phoenix</u>	<u>Sparrow</u>	<u>Sidewinder</u>
VF-1	.60	.90	.21
VF-2	.42	.74	.26
VF-3	.45	.72	.21
VF-4	.50	.60	.23
VF-5	.35	.70	.24
VF-6	.65	.80	.30
VF-7	.50	.76	.24
VF-8	.58	.78	.31
Fleet Average	.50	.75	.25

NOTE: These contrived data illustrate the format of results that PORA has obtained from the FOX ONE data base.

Table 7 is an example of the report format that PORA gives for the force defense role (see Annex C-3 for the details of the calculations that lead to Table 7). It is based on the scenario that was partially described in the preceding section:

- each squadron provides two sorties of FORCECAP for each of seven daily deck cycles,
and
- these sorties are to be fully mission capable, if possible.

We now give an additional description of the scenario as it applies to the F-14's force defense role:

- There are four CAP stations, two filled by the squadron of interest and two by its sister squadron;
- Each CAP aircraft is responsible for a 90-degree sector;
- If an enemy attack (bomber and/or missile) comes through a CAP sector, the aircraft in that sector has an opportunity to fire two Phoenix missiles, one Sparrow, and one Sidewinder;
- A fighter with less than FMC availability cannot fire Phoenix; and
- The fighter in the neighboring sector (assumed to be in the same squadron) crosses into the penetrated sector and has an opportunity to fire one Sparrow and one Sidewinder.

This report format (Table 7) permits the Commanding Officer of VF-1 to note that his squadron's overall performance is better than the fleet average of 2.95 targets killed. However, he will also note that VF-1 is below the fleet average in kills by the Sidewinder missile. This result suggests a shift in emphasis for VF-1's subsequent training.

TABLE 7: NUMBER OF BOMBERS KILLED
(GIVEN AN ENEMY ATTACK)

Squadron	Probability		Targets Killed by			Total Targets Killed
	Aircraft on Station		Missile			
	FMC	MC	Phoenix	Sparrow	Sidewinder	
VF-1	.90	.10	1.08	1.80	0.42	3.30
VF-2	.64	.36	.54	1.48	.52	2.54
VF-3	.99	.01	.90	1.44	.42	2.76
VF-4	.85	.15	.85	1.20	.46	2.51
VF-5	.92	.08	.65	1.40	.48	2.53
VF-6	.97	.03	1.26	1.60	.60	3.46
VF-7	1.00	—	1.00	1.52	.48	3.00
VF-8	1.00	—	1.16	1.56	.62	3.34
Fleet						
Average	.95	.05	.95	1.50	.50	2.95

The report format in Table 7 also permits the wing commanders to compare their subordinate squadrons to each other and to the fleet average. VF-2 and VF-3 can be identified as the weakest squadrons in this mission. The wing commander can further consult reports in the format of Tables 5, 6, and 7 to determine the reasons. As pointed out in the discussion of Table 5, VF-2 has poor aircraft availability that, in turn, leads to non-FMC aircraft in a demanding role. However, the report in Table 5 clearly indicates that FMC availability is not a problem with VF-3. The wing commander will quickly determine that VF-3 has below average performance in firing all three types of missiles. The wing commander's remedy is not to help VF-3 increase aircraft availability. Rather, it is to provide resources that will improve its missile firing performance.

Results and Reports for the Escort Role

Ketron has examined eight of the "Blue Baron" books reporting on exercises at the TACTS. The data are derived from a mixture of encounters with various odds (2 v 1, 2 v 2, 4 v 2, etc). It would obviously be incorrect to compare one aircrew's performance in 2 v 1 encounters with another aircrew's 2 v 2 encounters. Accordingly, we have stratified the TACTS data on the basis of the odds of the encounters.

With the data currently in hand, we have reasonably large data bases for the 2 v 1 and 2 v 2 encounters. We confine the present PORA largely to encounters at these odds; but as more data accumulate, we will be able to exploit data from encounters with other odds.

Table 8 gives the overall results for F-14 aircrews

TABLE 8: RESULTS OF EIGHT EXERCISES AT THE TACTS

<u>Odds</u>	<u>Loss Rate per Encounter</u>		<u>Exchange Ratio</u>
	<u>Red</u>	<u>Blue</u>	
2 v 1	.78	.15	5.1
2 v 2	.85	.62	1.4

TABLE 9: RESULTS OF 2 v 1 ENCOUNTERS FOR VF-1

<u>Aircrew</u>	<u>Loss Rate per Encounter</u>		<u>Exchange Ratio</u>
	<u>Red</u>	<u>Blue</u>	
A	1.00	.00	--
B	1.00	.00	--
C	1.00	.00	--
D	1.00	.00	--
E	.71	.29	2.5
F	.71	.29	2.5
G	.50	.00	--
H	.50	.00	--
I	.40	.60	0.7
J	.62	.38	1.7
K	1.00	.00	--
Squadron Average	.74	.19	4.0
Fleet Average	.78	.15	5.1

NOTE: See Annex C-1

during eight exercises at the TACTS. In the 2 v 1 encounter, a Blue aircraft shot down the Red aircraft in 78% of the encounters, and Blue suffered .15 losses per encounter. These results give an exchange ratio of 5.1 Red losses to 1 Blue loss. In the 2 v 2 encounters, Blue shot down slightly more Red aircraft per encounter (.85 vs .78), primarily because more targets were available. However, the stronger opposition shot down many more Blue aircraft per encounter (.62 vs .15). The exchange rate for the 2v2 encounters is still favorable to Blue, but it dropped from 5.1 to 1.4 due to the increased opposition.

The results in Table 8 give fleet average data from these TACTS exercises. PORA compares the results for individual aircrews against these fleet norms. Table 9 shows a report format that PORA provides to a squadron CO, comparing his pilots to each other and to the fleet average. The data in this table are real, but the identity of the squadron and the aircrews have been disguised at the request of COMFITWING ONE.

We see that VF-1's overall performance is slightly below the fleet average. The commanding officer can evaluate this overall comparison in light of qualitative factors. For example, the squadron might have been forced to run its exercise prematurely (earlier in the training cycle than is desirable). In that case, VF-1 has clearly performed in a satisfactory way for its state of training. As another example, the squadron might have been composed almost entirely of experienced pilots and NFOs who have completed at least one cruise. In this case, one would anticipate a better than average performance for VF-1 (because most squadrons have a considerable number of recent replacement squadron graduates) and the squadron's below average performance would be cause for concern.

The commanding officer can also review the performance of individual aircrews from a report such as this. He can see that most of his crews have done well. However, Crew I has done poorly. Again, he should apply judgment in comparing these results. For example, crew I might have been a pickup crew that had never flown together. Nevertheless, this report format should help the CO arrange his training priorities.

Table 10 is a similar report format for the wing commander level. Again, the data are real, but the identity of individual squadrons have been disguised. The wing commander also should exercise judgment in assessing the results. He should also examine similar PORA reports for encounters conducted with different odds (2 v 2, 4 v 2, etc.). Such a broader based comparison diminishes the impact of anomalous results that can arise from limited data samples at any given set of odds. For example, VF-7 performed commendably by losing no aircraft in the 2 v 1 encounters. However, VF-7 may have conducted an unusually small number of 2 v 1 encounters in its exercise at the TACTS. We can confirm their excellence if the exchange ratio is also relatively high for 2 v 2 and 4 v 2 encounters.

Now we combine the PORA estimates of ACM proficiency with the PORA estimates of sortie generation capability. The combination of these two subsidiary MOPs gives us the principal MOP for the escort role. We estimate how many enemy interceptors can be killed by the squadron (in a specified scenario). We also estimate the number of losses suffered by the F-14 squadron in the escort role in a similar format.

Table 11 shows the results of combining the two

TABLE 10: SQUADRON RESULTS FOR 2 v 1 ENCOUNTERS

<u>Squadron</u>	<u>Losses per Encounter</u>		<u>Exchange Ratio</u>
	<u>Red</u>	<u>Blue</u>	
VF-1	.74	.19	4.0
VF-2	.50	.71	0.7
VF-3	.74	.12	6.3
VF-4	.86	.21	4.2
VF-5	.95	.09	10.9
VF-6	.82	.12	6.8
VF-7	.80	0	--
VF-8	.66	.16	4.2
Fleet Average	.78	.15	5.1

NOTE: There are only six F-14 squadrons in the Atlantic Fleet. Some have conducted two exercises at the TACTS. They have been treated as separate squadrons for this illustration in order to keep their identities disguised.

TABLE 11: ENEMY INTERCEPTORS KILLED AND PENETRATING (PER DAY), ONE INTERCEPTOR AGAINST EACH STRIKE GROUP

Squadron Responsible for Escort	No of Escort Missions Flown ¹	Interceptors Killed per Encounter ²	Daily Avg. No of Interceptors ³	
			Killed	Penetrating
VF-1	2.96	.74	2.19	1.31
VF-2	1.96	.50	0.98	2.52
VF-3	3.12	.74	2.31	1.19
VF-4	3.28	.86	2.82	0.68
VF-5	3.45	.95	3.28	0.22
VF-6	2.12	.82	1.74	1.76
VF-7	3.45	.80	2.76	0.74
VF-8	3.28	.66	2.16	1.34
Fleet Average	2.96	.78	2.31	1.19

1 See Table 5.

2 See Table 10 (2 v 1 encounters).

3 See Annex C-4.

subsidiary MOPs. These results follow from the scenario previously described in the discussion of sortie generation:

- Each F-14 squadron launches two FORCECAP sorties on every cycle;
- Excess sortie generation capability is used to send sections of F-14s as escorts for a strike group; and
- In the absence of fighter escort, some groups of strike aircraft fly unescorted (one strike per cycle).

As our first example, we add one more element to the scenario:

- One enemy interceptor approaches each group of strike aircraft. Thus, the F-14's proficiency in 2 v 1 encounters should be used in the PORA analysis.

The wing commander reviewing the report in Table 11 will see that VF-6 and VF-8 are both below average in the escort mission. However, this PORA report allows him to tailor his remedial action to the specific weakness of each squadron. Table 11 shows that VF-8 has an above average sortie generation capability, but its ACM proficiency is below average. However, VF-6 has a below average sortie generation capability and an above average ACM proficiency. VF-6 appears to need resources that will increase its aircraft availability and sortie rate. But VF-8 appears to need additional training in ACM.

The Navy operational commander should be able to assess performance under several scenarios. Therefore, PORA's analytic machinery has been designed to give the commander this flexibility. To illustrate, we give another example with a modified scenario. The enemy is still assumed to send an average of 3.5 interceptors per day against the strike groups supposed to be escorted by each F-14 squadron.

However, we now assume that the enemy adopts a strategy of concentrating his forces. He only attempts to intercept half of the strike groups. When he does attempt an intercept, he does so with a pair of interceptors. The enemy randomly selects the strike groups to be attacked, so that we cannot predict which strikes are to be intercepted. We attempt to escort as many strike groups as possible with a section of F-14s. If the escorts are unavailable, the strike group proceeds alone.

Table 12 is a PORA report that presents the results for this modified scenario. In general the enemy has greater success in this modified scenario due to his concentration of forces. However, on a per encounter basis VF-3 does substantially better here than in the original scenario, both in an absolute sense and relative to the other squadrons. This illustrates a point made earlier, the commander should not restrict his attention to PORA performance estimates at 2 v 1 odds. VF-3 would have been unfairly judged by such a restriction. Thus, it is prudent to examine performance estimates under several scenarios.

PORA can prepare similar reports for a wide variety of strike escort scenarios (as selected by the operational commander). Similar report formats can present the aggregated results of sister squadrons. Such reports give the air wing commander and higher echelons of command an estimate of the overall fighter escort performance of the air wing.

TABLE 12: ENEMY INTERCEPTORS KILLED AND PENETRATING (PER DAY),
TWO INTERCEPTORS AGAINST HALF OF THE STRIKE GROUPS

Squadron Responsible For Escort	# of Escort Missions Flown ¹	# of Escorted Groups Opposed	Interceptors Killed per ² Encounter	Daily Average No. of Interceptors ³	
				Killed	Penetrating
VF-1	2.96	1.48	1.12	2.38	1.25
VF-2	1.96	.98	.88	2.62	1.74
VF-3	3.12	1.56	1.75	1.75	.01
VF-4	3.28	1.64	1.05	2.45	1.40
VF-5	3.45	1.73	1.33	2.17	0.84
VF-6	2.12	1.06	1.19	2.31	1.13
VF-7	3.45	1.73	1.48	2.02	0.53
VF-8	3.28	1.64	1.13	2.37	1.24
Fleet Average	2.96	1.48	1.26	2.24	0.98

- 1 See Table 5.
2 Data similar to Table 10, but for 2v2 encounters.
3 See Annex C-5.

APPENDIX A
DISCUSSION OF PORA MODELS
FOR THE A-7 AIRCRAFT

Annex A-1: Estimating and Projecting the CEP of Individual
Pilots

Annex A-2: Calculation of Kill Probability from CEP Data

Annex A-3: Calculation of the Fraction of a Target Mix
Killed Per Day

Annex A-4: Mathematical Derivation of Dive-Bombing Learning
Curve

ANNEX A-1

ESTIMATING AND PROJECTING THE CEP OF INDIVIDUAL PILOTS

The most widely used measure of weapon delivery accuracy is circular error probable (CEP). The CEP for a pilot is defined as the radius of a circle, inside which half of his bomb impacts will be found. This definition applies when the bombs are delivered one at a time. If bombs are delivered in strings or salvos, then the mean impact point (or the impact of the first bomb in the string, depending on the pilot's intent) must be used. Each string or salvo gives only one miss distance measurement. In other words, the CEP is the median miss distance measured from intended to actual impact point.

If the CEP is static and unchanging with time, then we can estimate it empirically as follows:

1. When there are an odd number of measurements, the CEP is estimated to be the middle one (when the miss distances are arranged from smallest to largest).
2. When there are an even number of measurements, the CEP is estimated to be half way between the two middle measurements (again, ordered from smallest to largest.)

For example, suppose a pilot records the following miss distances: 15, 4, 26, 8, and 12. His empirical CEP is 12. He has two miss distances larger than 12 and two that are smaller. If he drops another bomb and scores a miss of 16, then his CEP rises to 13.5 (halfway between 12 and 15). He now has three miss distances less than 14 and three

greater than 14. These empirical CEPs are statistical estimators of the pilot's true, but unknown, CEP: his median miss distance should he drop an infinite number of bombs.

In PORA, we encounter the problem of small sample sizes, especially early in the training cycle. For example, a pilot who dropped only one bomb and scored a bullseye has an empirical CEP of 0. However, we would not wish to predict that half of this pilot's future hits will be bullseyes on the basis of this single observation. Similarly, it would be silly to project a 950-meter CEP for a pilot who scored a single miss at that distance.

In PORA, we use a technique known as Bayesian statistics to alleviate the problem. This technique makes use of a "prior estimate" of the CEP. It seems appropriate to use historical data for this estimate. Thus, PORA uses the historical fleet average as its prior estimate. The pilot's actual scores are weighted in proportion to their number. The prior estimate has a preassigned weight that does not change with the number of observed scores. Thus, the estimated CEP for a pilot with many scores will be very close to his empirical CEP. However, the CEP estimated by PORA is shifted substantially toward the fleet average for pilot's with only a small number of actual scores. In fact, a pilot with no scores will be assigned the fleet average CEP until he has recorded at least one miss distance.

The mathematical details of the computation of CEP are as follows:

The bomb impacts are assumed to be distributed in a circular normal fashion about the target. Thus, the radial

density of impact is described by the Raleigh distribution (of parameter $\underline{\sigma}$):

$$f(R|\underline{\sigma}) = \frac{R}{\sigma^2} \cdot \exp \left[-\frac{1}{2} \left(\frac{R}{\sigma} \right)^2 \right] \quad (\text{A-1-1})$$

The density of a sample of radial misses r_i ($i = 1, 2, \dots, n$) is then

$$f(R|\sigma) = \frac{\prod_{i=1}^n r_i}{\sigma^{2n}} \cdot \exp \left[\frac{\sum_{i=1}^n r_i^2}{2\sigma^2} \right] \quad (\text{A-1-2})$$

The notation can be simplified with the following substitutions.

$$\alpha = \prod_{i=1}^n r_i ,$$

$$\beta = \frac{1}{2} \sum_{i=1}^n r_i^2 , \text{ and}$$

$$Q = \frac{1}{\sigma^2} .$$

We then obtain:

$$f(R|Q) = \alpha Q^n \exp (-\beta Q) . \quad (\text{A-1-3})$$

Our data on the distribution of CEPs among pilots is of the form shown in Figure A-1-1. There are no negative CEPs and a few small positive CEPs exist. However, there is also

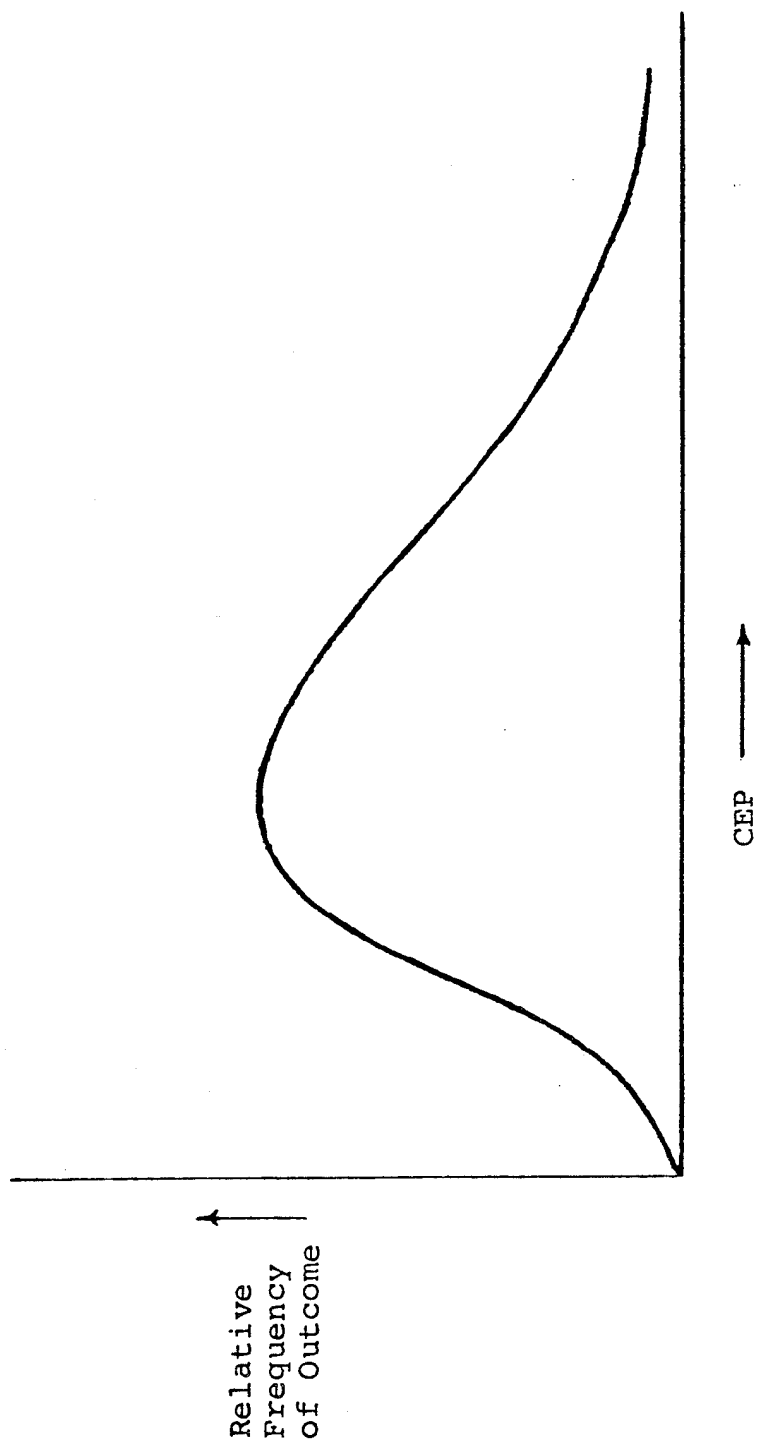


FIGURE A-1-1: DISTRIBUTION OF CEPs

a long "tail" of large CEPs beyond the modal value.

This general shape suggests a gamma density function. The gamma density has two adjustable parameters, λ and m . The values of these parameters may be jointly selected to give a distribution that matches the mean and standard deviation of the distribution reflecting the CEPs of all fleet pilots.

An appropriate prior distribution is then the gamma density function of the following form:

$$g(Q) = \frac{1}{m!} \cdot \lambda^{m+1} \cdot Q^m \cdot \exp(-\lambda Q) . \quad (A-1-4)$$

For reasons that will become apparent later, we let

$$\lambda = m\sigma_0^2 . \quad (A-1-5)$$

Now, we invoke Bayes theorem to estimate a posterior density function:

$$F(Q|R) = K \cdot f(R|Q) \cdot g(Q) , \quad (A-1-6)$$

when K is a constant of normalization. Thus,

$$F(Q|R) = K \cdot \alpha \cdot Q^n \cdot e^{-\beta Q} \cdot \frac{[m\sigma_0^2]^{m+1}}{m!} \cdot Q^m \cdot e^{-m\sigma_0^2 Q} \quad (A-1-7)$$

or,

$$F(Q|R) = K' Q^{m+n} e^{-(m\sigma_0^2 + \beta) Q} , \quad (A-1-8)$$

Now let:

$$M = m + n, \text{ and} \quad (\text{A-1-9})$$

$$\theta = m\sigma_0^2 + \beta \quad (\text{A-1-10})$$

Then,

$$f(Q|R) = K' Q^M e^{-\theta Q}, \quad (\text{A-1-11})$$

or

$$f(Q|R) = K'' \cdot \frac{\theta^{M+1} Q^M}{M!} \cdot e^{-\theta Q}, \quad (\text{A-1-12})$$

where K' and K'' are normalization constants.

By integrating the preceding equation from $Q = 0$ to $Q = \infty$, we find that $K'' = 1$. Thus,

$$f(Q|R) = \frac{\theta^{M+1} Q^M}{M!} \cdot e^{-\theta Q}$$

Since,

$$\sigma = Q^{-\frac{1}{2}}$$

we calculate the expected value of σ as follows:

$$\begin{aligned} \varepsilon(\sigma) &= \int_0^\infty Q^{-\frac{1}{2}} \cdot f(Q|R) dQ, \\ &= \int_0^\infty \frac{\theta^{M+1} Q^{M-\frac{1}{2}}}{\Gamma(M+1)} \cdot e^{-\theta Q} dQ, \end{aligned}$$

or

$$\varepsilon(\sigma) = \frac{\Gamma(M+\frac{1}{2})}{\Gamma(M+1)} \cdot \theta^{\frac{1}{2}} \int_0^{\infty} \frac{\theta^{M+\frac{1}{2}} \cdot Q^{M-\frac{1}{2}}}{\Gamma(M+\frac{1}{2})} \cdot e^{-\theta Q} dQ . \quad (A-1-13)$$

The integral in the preceding expression is unity (from the properties of the gamma function), and

$$\varepsilon(\sigma) = \frac{\Gamma(M+\frac{1}{2})}{\Gamma(M+1)} \theta^{\frac{1}{2}} . \quad (A-1-14)$$

Similarly, we can calculate

$$\begin{aligned} \varepsilon(\sigma^2) &= \varepsilon(Q^{-1}) \\ &= \int_0^{\infty} Q^{-1} \cdot f(Q|R) \cdot dQ , \end{aligned}$$

or

$$\varepsilon(\sigma^2) = \theta/M . \quad (A-1-15)$$

We are now in a position to calculate the variance of the posterior distribution:

$$\text{Var}_{\text{Post}} = \varepsilon(\sigma^2) - [\varepsilon(\sigma)]^2 , \quad (A-1-16)$$

or

$$\text{Var}_{\text{Post}} = \left\{ \frac{1}{M} - \left[\frac{\Gamma(M+\frac{1}{2})}{\Gamma(M+1)} \right]^2 \right\} \cdot \theta . \quad (A-1-17)$$

By setting $n = 0$, we may use the preceding results to estimate the mean and variance of the prior distribution.

The data for fleet pilots indicate that the standard deviation is equal to about one-third of the mean of the distribution of CEPs. By selecting $m = 2$, we obtain a ratio of .341. With this value of m , we set the quantity .094 equal to the fleet average and our gamma density function has been fitted to the data.

Non-Static CEPs

The empirical CEP, like all other statistical estimators, must be applied carefully to avoid "apples and oranges" comparisons. Thus, we should not mix dive bombing data with toss bombing data, nor day drops with night, nor system deliveries with manual deliveries. We avoid these problems by calculating a separate CEP for each bombing mode.

A related problem is that a pilot's CEP (or σ) is not static in time. Like the results of most activities of skill, bombing scores exhibit a learning curve. CEPs tend to decline over time when the pilots have the opportunity to practice. Additionally, the learning curves may be different for pilots of varying experience levels. PORA accommodates these factors by normalizing bombing scores to a learning curve appropriate to pilots of similar experience (first squadron tour, second tour and third tour).

Figure 6 of the main text shows the overall monthly dive bombing CEP of an A-7E squadron throughout its training turnaround cycle. In the absence of other historical data, we have used these data as the "fleet average" for purposes of this initial PORA project. As PORA continues to accumulate delivery accuracy data, the historical data base will be continually updated.

A least squares procedure was used to select a learning curve of the following form:

$$\text{CEP}(t) = 10 + Ke^{-\lambda t} \quad (\text{A-1-18})$$

where

t = time (in months) into the turnaround cycle;

$\text{CEP}(t)$ = average CEP (in meters) at time t ,

K = a constant to be determined, and

λ = a constant to be determined.

The least squares procedure gives a value of

$K = 19.2$ meters and

$\lambda = .120$ per month.

The learning curve thus gives a CEP of 29.2 meters for the average pilot at the beginning of the turnaround cycle. The CEP declines asymptotically to 10 meters (assumed to be the approximate limit imposed by ballistic dispersion for dive bombing).

At the present time we have insufficient data to estimate separate learning curves for pilots of various experience levels. To demonstrate the capability of using more than one learning curve we have arbitrarily assumed a slightly better performance for the more experienced pilots. Thus, our algorithm estimates the CEPs for individual pilots by use of equation (A-1-13), but normalizing to a prior estimate in the form of equation (A-1-18) with the following parameter values:

$$K = \begin{cases} 18 \text{ meters for third tour pilots,} \\ 19 \text{ meters for second tour pilots, and} \\ 20 \text{ meters for first tour pilots} \end{cases}$$

and

$$\lambda = 0.1198 \text{ per month.}$$

ANNEX A-2

CALCULATION OF KILL PROBABILITY FROM CEP DATA

A pilot's bombing CEP is a good single-number measure of his bombing ability. However, the CEP does not by itself give his probability of killing a specified target with a single delivery pass.

The kill probability (P_k) depends on the number and type of weapons dropped from the aircraft. The P_k also depends on the size, shape, and hardness of the target. The official document for estimating kill probabilities is the Joint Munitions Effectiveness Manual (JMEM). This document gives the P_k s for the most common weapon loadings against a wide variety of targets. These tabulated P_k s assume a standard value of CEP for each weapon and delivery mode. These standard CEPs are based on estimates of the performance of the average pilot. Appendix C of the JMEM also gives the methodology that can be used to calculate P_k for variations in CEP, weapon loadings, and targets not included in the tabulations of the JMEM.

In PORA, we are interested in the variation of CEP between pilots. Because no individual pilot has precisely the standard CEP assumed by the JMEM, future PORA will rely on the JMEM methodology (rather than JMEM tabulated results) to estimate P_k s for individual pilots. However, this methodology is cumbersome, and we have used simplified methods for this pilot project for PORA. After the target mixes for PORA have been agreed upon, these simplified methods of calculation will be replaced by the full JMEM methodology.

In this report we have restricted the target mixes to only six types of targets. We have also restricted the

weapon loading to a single MK 83 bomb. In practice, a string of several bombs would probably be delivered, and the P_k s would be larger than those calculated here. However, this report illustrates the type of results that PORA can provide for a spectrum ranging from small hard targets to large soft targets. It would have been inefficient, considering the limited time available for this pilot project, to examine a larger number of target types and weapon loadings, and to use the full methodology recommended in the JMEM.

The simplified methodology in this pilot project considers the following six targets:

1. Light tank,
2. Heavy tank,
3. Bridge,
4. Small building,
5. Large building, and
6. Truck park.

Each pilot's delivery accuracy is assumed to be described by a circular normal distribution. The fraction (F) of his bombs placed inside a circle of radius R is thus given by

$$F = 1 - \exp \left[-\frac{1}{2} (R/\sigma)^2 \right] . \quad (A-2-1)$$

Here, the parameter σ is a characteristic of the individual pilot. It is related to the pilot's CEP as follows:

$$\sigma = \text{CEP}/1.1774. \quad (A-2-2)$$

Thus, if we have an estimate of a pilot's CEP, we can calculate his σ from equation (A-2-2). If the target is circular (or nearly so), then equation (A-2-1) gives the bomb-fraction of impacting inside the target area.

If the target is rectangular, then the well known properties of the normal distribution may be used to estimate this fraction. First we estimate the fraction of bombs impacting within the target's width, then the fraction impacting within the target's length. The product of these two fractions is the fraction of impacts falling within the rectangular target area.

We must also consider the "conditional kill probability" (C). That is the probability that the target is killed, given that the bomb impacts within the circular or rectangular target area. The P_k is then obtained from the product of the fraction of impacts and the conditional kill probability:

$$P_k = C \cdot F$$

(A-2-3)

For this report, we have assumed the parameter shown in Table A-2-1.

These targets have been arranged in generally increasing order of size. Thus, for a given CEP, those at the top of the list are harder to hit than those at the bottom. We can now select target mixes of varying degrees of difficulty by shifting the proportions of the six targets.

TABLE A-2-1: CONDITIONAL KILL PROBABILITIES
FOR TYPICAL TARGETS

<u>Target</u>	<u>Equivalent Area of Target Augmented by Lethal Radius of Bomb</u>	<u>Conditional Kill Probability</u>
Light Tank	Circle, 3-meter radius	1.0
Heavy Tank	Rectangle, 5 x 9 meters	.9
Bridge	Rectangle, 3 x 100 meters	.5
Small Building	Rectangle, 10 x 12 meters	.9
Large Building	Rectangle, 20 x 25 meters	.75
Truck Park	Park is circular (50 meter radius), density of trucks gives C=.2 if bomb impacts in circle.	.2

ANNEX A-3

CALCULATION OF THE FRACTION OF A TARGET MIX KILLED PER DAY

One of the principal outputs of PORA is the target killing capability of a squadron or wing per day. To this end, we chose three target mixes, as shown in Table A-3-1.

Each target mix includes one light tank and one heavy tank. However, Mix A generally consists of the smaller and harder to hit targets (3 bridges, but only two trucks). Mix C generally consists of the larger and easier to hit targets.

The previous section indicated how we calculated the P_k of a given pilot against a specified target. We denote the P_k for the i^{th} pilot against the j^{th} target as P_{ij} . We assume that each pilot flies the same number of sorties against each type of target. Thus, the average P_k for a squadron against targets of type j is

$$P_{\cdot j} = \frac{1}{n} \sum_{i=1}^n P_{ij} , \quad (\text{A-3-1})$$

where n is the number of pilots assigned to the squadron. The expected number of sorties (S_j) to destroy a target of type j is the reciprocal of this probability:

$$S_j = 1/P_{\cdot j} \quad (\text{A-3-2})$$

TABLE A-3-1: THE TARGET MIXES

<u>Type of Target</u>	<u>Number of Targets of Specified</u>		
	<u>Mix A</u>	<u>Mix B</u>	<u>Mix C</u>
Light Tanks	1	1	1
Heavy Tanks	1	1	1
Bridges*	3	1	0
Small Buildings	3	5	2
Large Buildings*	2	1	0
Truck Park	2	10	12

*Target suitable for Walleye under appropriate visibility conditions.

For a target mix consisting of N_j targets of type j , then the expected number of sorties (S_{mix}) to kill the mix is:

$$S_{mix} = \sum_{j=1}^6 S_j \cdot N_j. \quad (A-3-3)$$

The average fleet squadron is assumed to consist of two third-tour pilots, four second-tour pilots and ten first-tour pilots. Each of these pilots is assumed to have a CEP taken from the fleet average learning curve for the appropriate point in the training cycle. These CEPs are used to calculate the P_k s in equation (A-3-1) for the "fleet average" squadron.

ANNEX A-4

MATHEMATICAL DERIVATION OF DIVE-BOMBING LEARNING CURVE

Figure 6 of the main text shows the improvement in bombing accuracy for a squadron during its turnaround training cycle. The squadron's bombing CEP is plotted for each of the ten months in the cycle. We have fitted a curve through these points and used it as "the historical fleet data base" for purposes of this initial A-7 PORA effort. This annex discusses the curve fitting procedures used in this analysis.

The limits of the A-7 bombing system and ballistic dispersion prevent CEPs from going to zero. In this preliminary PORA analysis, we assume that the learning curve approaches a 10-meter CEP for dive-bombing after a long training period. This assumption will be reviewed as PORA continues to accumulate A-7 accuracy data. We assumed a learning curve of the following functional form:

$$C(t) = 10 + K \exp(-\lambda t). \quad (A-4-1)$$

Here,

t = time (in months) = 1, 2, ...10;

C = squadron CEP (in meters);

K and λ are constants to be determined.

We now proceed to evaluate the unknown values of K and λ from the data. We do so by minimizing the sum of squares (S) between the observed and calculated values of CEP:

$$S = \sum_{t=1}^{10} [C(t) - 10 - K \exp(-\lambda t)]^2 \quad (A-4-2)$$

For a given value of λ , the sum of squares is minimized when

$$\frac{\partial S}{\partial K} = 0. \quad (A-4-3)$$

Evaluation of this partial derivative and algebraic manipulations then yields

$$K^*(\lambda) = \frac{\sum (C_t - 10)}{\sum e^{-2t}}. \quad (A-4-4)$$

Here K^* is the value of K that minimizes the sum of squares.

The sum of squares must also be minimized with respect to λ :

$$\frac{\partial S}{\partial \lambda} = 0. \quad (A-4-5)$$

Unfortunately, equation (A-4-5) does not lead to an analytic solution for λ . Therefore, our curve-fitting procedure used a combination of analytic and trial and error techniques.

We started out by guessing a value (λ_0) for the decay parameter in our functional form. Then we use equation (A-4-4) to find

$$K_0 = K^*(\lambda_0). \quad (A-4-6)$$

We then calculate

$$S_0 = S(K_0, \lambda_0). \quad (A-4-7)$$

Then we use an iterative process to continue the search for the values of K and λ that simultaneously minimize the sum of squares (equation (A-4-2)). We arbitrarily select a new value λ and, using equation (A-4-4), its corresponding value K , and the sum of squares

$$S_1 = S(K_1, \lambda_1). \quad (A-4-8)$$

We continue with a "bracket and halve" process until the minimum sum of squares has been determined to an appropriate degree of precision. The values of K and λ that produce this minimum are then our "least squares" estimates. These are

$$K = 19.2 \text{ meters,}$$

$$\lambda = .120 \text{ per month.}$$

These estimated values imply that the CEP is about 29.2 meters ($10 + 19.2$) when the squadron begins its training cycle. This CEP drops exponentially with time towards an asymptote of 10 meters.

APPENDIX B
MATHEMATICAL DEVELOPMENT OF THE
SORTIE GENERATION MODEL

Annex B-1: General Model Description

Annex B-2: Validation of the Sortie Generation Model

Annex B-3: The Projection of a Squadron's Availability Rate

ANNEX B-1

GENERAL MODEL DESCRIPTION

In this project we have used a sortie generation model to estimate the number and type of sorties that can be flown by a squadron. This sortie generation capability is calculated from aircraft availability, the probability of downing a returning aircraft, repair capabilities, and the schedule being attempted. The model is an improved version of a sortie generation model originally developed at the Center for Naval Analyses for the Sea-Based Air series of studies.

Figure B-1-1 illustrates a typical computer run of the sortie generation model. At the top of the computer printout is a summary of the inputs used for this run. Here we have specified an 8-cycle "flex deck" flying day. The launch intervals are 90 minutes and the mission times slightly longer, 105 minutes (because aircraft for the new cycle are always launched before aircraft are recovered from the old cycle). A returning aircraft that is not downed may be turned around (refueled, rearmed, and appropriately spotted on the deck) 50 minutes after recovery.

An average aircraft availability at the start of the flying day of .64 has been specified. This reflects an average mission capable (MC) availability for deployed A-7 squadrons in 1979 (see Annex B-2). The probability that a returning aircraft is downed for maintenance is assumed to be .20. The number of aircraft possessed by the squadron has been set at 11.75, the average for deployed A-7 squadrons in 1979. The quantities IZ1 and IZ2 are computed from the inputs and indicate that an aircraft remaining "up"

This is a NORMAL SGM run .

NUMBER OF CYCLES	=	8
LAUNCH INTERVAL	=	90.00 MINUTES
MISSION TIME	=	105.00 MINUTES
TURN AROUND TIME	=	50.00 MINUTES
MTTR	=	260.00 MINUTES
A/C AVAILABILITY RATE, START OF DAY	=	.64
PROBABILITY OF DOWN ON RECOVERY	=	.20
TOTAL ON-BOARD A/C	=	11.75
IZ1 (CYCLES N/A - FLYING + TAT)	=	1
IZ2 (CYCLES N/A - FLYING)	=	1

REPAIR PROBABILITY BY CYCLE (LAUNCH)

CYCLE	1	2	3	4	5	6	7	8
INCREMENTAL	0.00	.10	.41	.21	.06	.04	.04	.01
CUMULATIVE	0.00	.10	.50	.72	.78	.82	.86	.87

RESULTS	LAUNCH CYCLE	MAX READY	SCHEDULE	FLOWN	AVAILABLE
	1	7.52	4.00	4.00	7.52
	2	3.52	2.00	2.00	6.72
	3	4.72	4.00	4.00	6.32
	4	2.40	2.00	2.00	5.60
	5	3.96	4.00	3.96	5.56
	6	2.01	2.00	2.00	5.18
	7	3.68	4.00	3.68	5.28
	8	2.07	2.00	2.00	5.01

TOTAL SORTIES SCHEDULED	=	24.00
TOTAL SORTIES FLOWN	=	23.64 (98.50 %)
AVERAGE NO. AVAILABLE	=	6.15 (52.33 %)
SORTIES/AVAILABLE A/C	=	3.85
SORTIES ON-BOARD A/C	=	2.01
A/C UP AT END OF DAY	=	6.99(59.48 %)
ADD A/C DOWN	=	.53

FIGURE B-1-1: TYPICAL INPUT AND OUTPUT FOR THE
SORTIE GENERATION MODEL

is available for relaunch one cycle after it returns from its previous sortie.

The second block of information in Figure B-1-1 indicates the repair capabilities assumed for the squadron. These inputs stem from the 260-minute MTTR specified in the inputs. This MTTR reflects data for high performance aircraft aboard a carrier deployed in the Mediterranean (collected by an OEG representative). The repair probabilities indicate that no downed returning aircraft will be ready for the next launch, but that 10% will be ready for the second launch after downing. Another 41% become ready for the third launch, another 21% for the fourth launch, etc.

The third block of information in Figure B-1-1 summarizes the sorties scheduled and flown in each cycle and indicates the number of aircraft in an available status (SCIR definition) and the number available for launch (a mission capable aircraft is not available for launch if it is still in the air from a previous launch). At the start of the flying day, there are 7.52 aircraft available and ready ($.64 \times 11.75$ aircraft). Our schedule calls for launching four aircraft and four are, in fact, launched. This leaves $7.52 - 4.00 = 3.52$ aircraft ready for launch in the second cycle. The schedule calls for launching two aircraft on the second cycle, and this part of the schedule is also feasible. However, the number of available aircraft has dropped to 6.72 (20% of the 4 aircraft returning in the first cycle, or .80 aircraft have been downed for maintenance). The computer shows that a sufficient number of aircraft are ready to launch the four aircraft scheduled for the third launch and the two scheduled for the fourth launch. The number of available aircraft continues to drop

due to the downing of 20% of the returning aircraft. However, this decrease is partially offset by the repair of some of the previously downed aircraft.

At the time for the fifth launch of the day, the squadron has 5.56 aircraft available on a mission capable status. However, some of these aircraft are still in the air and are not ready to launch. It is not possible to launch the scheduled four aircraft. The squadron does the best that it can and launches the 3.96 aircraft ready for launch. As the flying day continues, the squadron meets its schedule of two aircraft on the sixth and eighth launches, and it launches only 3.68 of 4 aircraft scheduled on the seventh cycle. The computer program continues to account for the repair of downed aircraft for the non-flying portion of the day, but the availability numbers are not shown after the time of the last launch.

The bottom block of information in Figure B-1-1 summarizes the results for the day. The squadron has flown 23.64 of 24 scheduled sorties (98.5%). The average availability is 6.15 aircraft (52.3%) over the 24-hour day. The squadron has flown 2.01 sorties per on-board aircraft and 3.85 sorties per available (average) aircraft. By the start of the next flying day 6.99 aircraft are available, a decrease of .53 aircraft from the start of the first flying day. The sortie generation model assumes that these .53 "hard down" aircraft are replaced by the repair of .53 of the 4.23 hard down aircraft that were not available during the first flying day.

The version of the sortie generation model allows the user to specify any of the inputs (including the desired schedule). The program then reports the number of sorties actually flown, by cycle and the daily total, and the

availability factor that would be reported in the SCIR system.

Another option for the sortie generation model allows the user to determine the maximum number of sorties that can be scheduled and flown. The model can also determine the number of aircraft flown in two or more types of missions (in specified priority order). It can also keep track of differing availability requirements (e.g., full mission capable and mission capable) for the various mission types.

ANNEX B-2
VALIDATION OF THE SORTIE GENERATION MODEL

The preceding section of this appendix described how the sortie generation model works. This section describes a validation of the model against 1979 fleet data.

We assume that the average squadron passes through a 15-month cycle: 9 months of training, followed by 6 months deployed. Table B-2-1 gives an approximate breakdown of the 15-month cycle for a typical squadron. The segments (OP-1, OP-2, etc.) are taken from the COMNAVAIRLANT's Air Wing Readiness Training Manual (INST 3500.42D).

The various flying schedules are shown in Figures B-2-1 and B-2-2. We ran the sortie generation model for most of these schedules with the results shown in Table B-2-2. We did not run the model for three of the less frequently used types of schedules: field carrier launching practice (FCLP), carrier qualification (CQ), and nuclear (Nuc). These schedules are somewhat irregular and difficult to use in the model, and we merely assumed the number of sorties and flight hours achieved for these 14 days of the 15-month cycle.

The results at the bottom of Table B-2-2 predict that 3,015 sorties and 5,142 hours would be flown by the average squadron in a 12-month period. These results are both about 1% higher than the average achieved by Atlantic A-7E squadrons in 1979. This discrepancy can be easily explained by sorties cancelled when pilots were not available to fly an available aircraft or by sorties cancelled due to weather conditions.

To validate the sortie generation model more fully, we

TABLE B-2-1: THE 15-MONTH CYCLE FOR A TYPICAL SQUADRON

<u>Segment</u>	<u>Schedule</u>	<u>Duration</u>	<u>Flying Days</u>
OP-1	Standdown	<u>1 month</u>	<u>19</u>
	Subtotals	1 month	19
OP-2	Normal Training	3 months	57
	Weapons Det.	2 weeks	10
	(FCLP) <u>2 weeks</u>	<u>10</u>	
	Subtotals	4 months	77
OP-3	(CQ)	1 week	3
	Afloat Training	1 week	5
	Standdown	<u>1 week</u>	<u>4</u>
	Subtotals	.75 months	12
OP-4	Afloat Training (TYT-1)	<u>2 weeks</u>	<u>10</u>
	Subtotals	.5 months	10
OP-5	Normal Training	<u>3 weeks</u>	<u>14</u>
	Subtotals	.75 months	14
OP-6	Afloat Training (TYT-2)	1 week	5
	Standdown (ashore)	1 week	4
	Afloat Training (TYT-3)	10 days	8
	Flex - ORE	2 days	2
	Alfa - ORE	1 day	1
	(Nuc) - ORE	<u>1 day</u>	<u>1</u>
	Subtotals	1 month	21

TABLE B-2-1: THE 15-MONTH CYCLE FOR A TYPICAL SQUADRON (CONT)

<u>Segment</u>	<u>Schedule</u>	<u>Duration</u>	<u>Flying Days</u>
OP-7	Standdown	<u>1 month</u>	<u>16</u>
	Subtotals	1 month	16
Transits No Fly		<u>1 month</u>	<u>0</u>
	Subtotals	1 month	0
Deployment	Afloat Training	52	
	Flex }	5 months	6
	Alfa }	<u>2</u>	
	Subtotals	<u>5 months</u>	<u>60</u>
Grand Totals		<u>15 months</u>	<u>229</u>

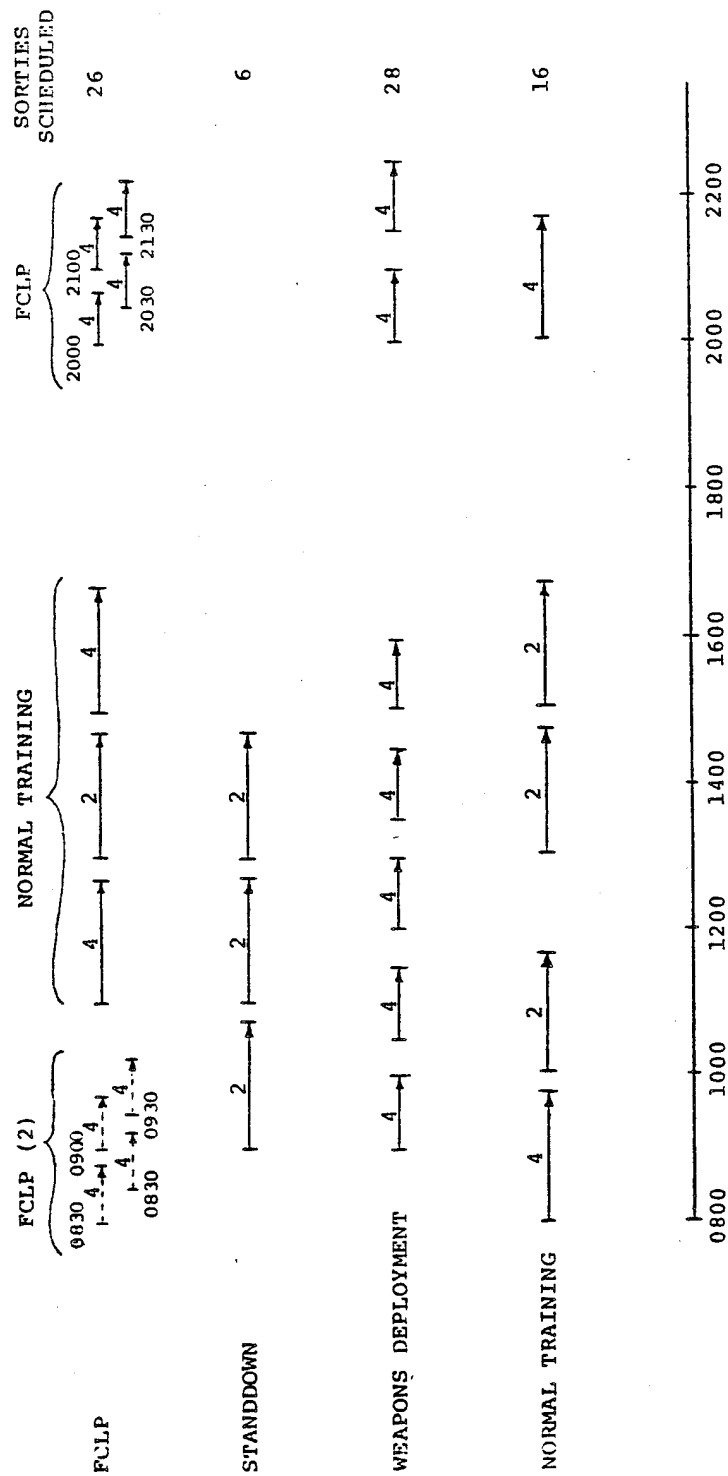


FIGURE B-2-1: A-7 SQUADRON -- TYPICAL ASHORE FLIGHT SCHEDULES

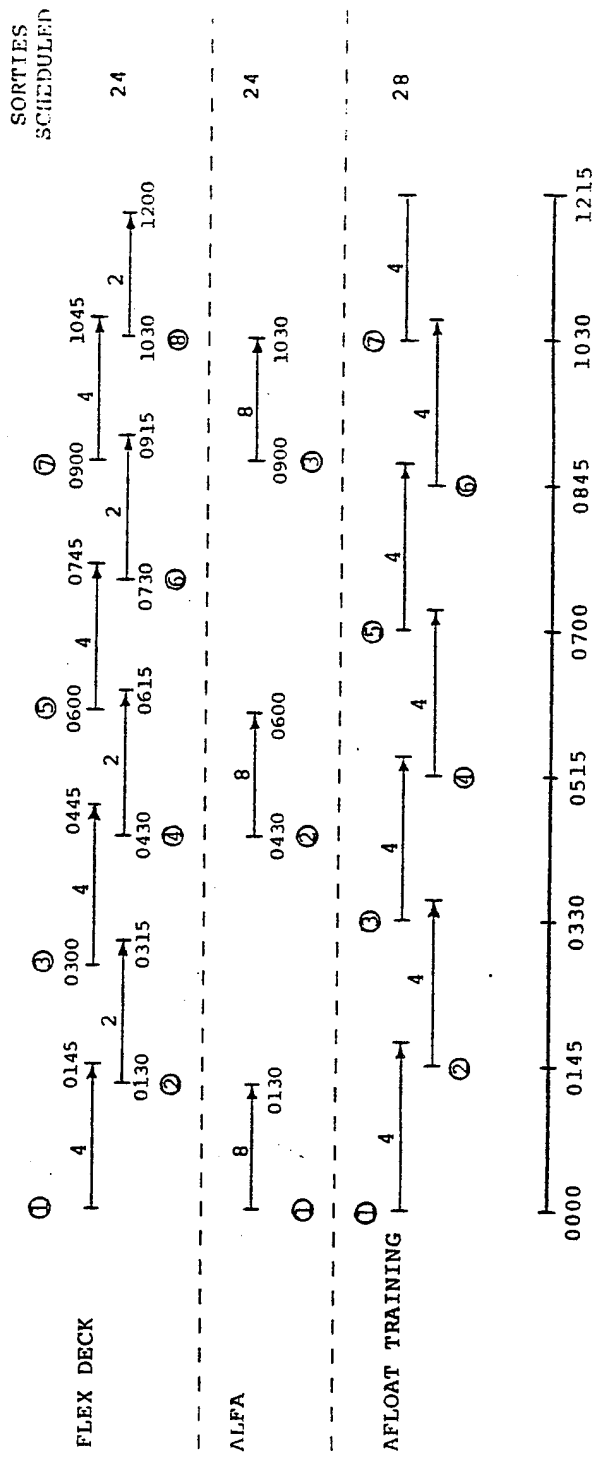


FIGURE B-2-2: A-7 SQUADRON -- TYPICAL AFLOAT FLIGHT SCHEDULES

TABLE B-2-2: RESULTS OF SORTIE GENERATION
MODEL FOR TYPICAL SCHEDULE

<u>Type of Schedule</u>	<u># of flying days</u>	<u>Sorties Flown per Flying day</u>	<u>Total Sorties</u>	<u>Hours per Sortie</u>	<u>Total Flying Hours</u>
<u>Non-deployed</u>					
<u>Ashore</u>					
Standdown	43	6	258	1.75	451.5
Training	71	14	994	1.5	1491
Weapons	10	23.65	236.5	1	236.5
(FCLP)	10	26	260	{ 1.75(10) .75(16)	295
<u>Afloat</u>					
Training	28	20.48	573.44	2	1146.88
Flex	2	22.00	44	1.75	77
Alfa	1	17.69	17.69	1.5	26.54
(CQ)	3	8	24	1.25	30
(Nuc)	1	7	7	2	14
No Fly	<u>105</u>	0	<u>0</u>	-	<u>0</u>
Totals	274		2,414.63		3,768.42

TABLE B-2-2: RESULTS OF SORTIE GENERATION MODEL
MODEL FOR TYPICAL SCHEDULE (CONT)

<u>Type of</u> <u>Schedule</u>	<u># of flying</u> <u>days</u>	<u>Sorties Flown</u> <u>per Flying Day</u>	<u>Total</u> <u>Sorties</u>	<u>Total</u> <u>Hours per</u> <u>Sortie</u>	<u>Flying</u> <u>Hours</u>
<u>Deployed</u>					
<u>Afloat</u>					
Training	52	22.55	1172.60	2	2345.2
Flex	6	23.64	141.84	1.75	248.22
Alfa	2	19.76	39.52	1.67	66.00
<u>No Fly</u>	<u>92</u>	<u>0</u>	<u>0</u>	<u>-</u>	<u>0</u>
Totals	152		1,353.96		2,659.42
Grand Totals (15 months)			3,768.59		6,427.84
			<u>x .8</u>		<u>x .8</u>
12 Month Equivalent			3,014.87		5,142.27
Fleet Average (1979)			2,984		5,080

NOTE: Sortie generation model not run for schedules indicated in parentheses (FCLP, CQ, Nuc).

now examine the availability statistics. The number of possessed aircraft used in the sortie generation model to produce Table B-2-2 was 11.75 for deployed squadrons and 11.41 for non-deployed squadrons. These numbers are the fleet averages for 1979. Availability at the beginning of the flying day was assumed to be .64 for deployed squadrons and .59 for non-deployed squadrons. The model computed the 24-hour average availability from these starting points for each of the schedules, except the non-flying days. The average fleet availability (mission capable) for 1979 was 57.9% for deployed squadrons and 53.8% for non-deployed squadrons. To match these year-average availabilities with our results (Table B-2-2) for flying days, the average availability on non-flying days would have to be 61.8% for deployed squadrons and 54.8% for non-deployed squadrons. These availabilities are both greater than the corresponding 24-hour average availabilities and below the corresponding start-of-the-flying-day availabilities. Thus, we conclude that the sortie generation model gives reasonable results.

ANNEX B-3

THE PROJECTION OF A SQUADRON'S AVAILABILITY RATE

The availability rates for aircraft in a squadron are not constant over time. Some of the variations are, of course, due to random fluctuations. Other variations in availability are systematic, varying somewhat predictably during the training cycle and deployment periods.

The PORA reports take the predictable variations into account for projections of future availability. This process is similar to the "seasonal adjustments" that are used in computing economic indicators. Our procedure is as follows.

The average MC availability for A-7 aircraft in 1979 was 57.9% for deployed aircraft and 53.8% for non-deployed aircraft. We use these two availability levels as the basis for our adjustment procedure.

To illustrate, suppose that SCIR data for two recent months gave the following data:

March (deployed)	57.1%,
April (non-deployed)	48.2 ,
May (non-deployed)	54.1 .

The PORA approach is to use the fleet average as a standard. In March, the squadron's availability was .986 ($57.1 \div 57.9$) of the deployed average availability. In the next two months, the squadron availability was .896 ($48.2 \div 53.8$) and 1.006 ($54.1 \div 53.8$) of the non-deployed standard.

We then average the three fractions:

$$\frac{.986 + .896 + 1.006}{3} = .963$$

Thus, the squadron's average availability has been .963 of standard availability. Our projections are for future deployment, so we estimate

$$.963 \times 57.9 = 55.8\%$$

for the squadron's future availability.

APPENDIX C
DISCUSSION OF PORA MODELS
FOR THE F-14 AIRCRAFT

Annex C-1: A Note on the Calculation of Red and Blue Loss Rates Per Encounter from TACTS Data

Annex C-2: Calculation of Intercept Performance from FOX ONE Data

Annex C-3: Calculations Supporting Table 7

Annex C-4: Calculations Supporting Table 11

Annex C-5: Calculations Supporting Table 12

ANNEX C-1

A NOTE ON THE CALCULATION OF RED AND BLUE LOSS RATES PER ENCOUNTER FROM TACTS DATA

The "Blue Baron" reports give data on each encounter during a squadron's exercise at the TACTS. It is a straightforward matter to tally the successful missile firings and determine the number of aircraft lost by each side. From this procedure, we can easily produce summary statistics for the squadron such as those in Figure 7 of the main text.

Complications arise when similar loss rate statistics are to be estimated for individual aircrews. This appendix describes the method we have used in deriving these aircrew statistics.

Whenever two or more F-14 aircraft fly together in an encounter, we regard their performance as a team effort. If an adversary (Red) aircraft is shot down, the PORA treats this event as a success for each of the F-14 (Blue) aircrews, regardless of which one pulled the trigger. Similarly, PORA treats the loss of a Blue aircraft as a failure for the aircrew shot down and for his wingmen. Our analysis assumes that proper tactics are designed to destroy the enemy and that wingmen should not compete with each other for the kill. We also assume that an aircrew executing proper tactics protects not only itself, but also its wingmen.

ANNEX C-2

CALCULATION OF INTERCEPT PERFORMANCE FROM FOX ONE DATA

The FOX ONE data base includes all of the recent air-to-air missile firing attempts by Atlantic Fleet aircraft. There are a large number of such attempts each year (more than 100 in the first half of this fiscal year). However, there are three different kinds of missiles and twelve fighter squadrons. Thus, the statistical sample size is small when we examine, say, the performance of VF-5 firing Sidewinder missiles.

We would not wish to estimate the squadron's P_k as unity if it had one opportunity and one success. Nor would we wish to estimate a P_k of zero if it had one opportunity and one failure. Fortunately, there is a mathematical procedure for modifying empirical estimates when several squadrons have each had a small number of firing opportunities.

The procedure is explained in the Scientific American, May 1977, pages 119-127. This article introduces in simple language the James-Stein estimators, which are explained with great rigor in the mathematical literature. Stein has shown that the observed ratio of successes to opportunities is not the "best" estimator of performance when there are data for three or more individuals (squadrons). James and Stein have developed the best estimator for such data (Note: Here the term "best" has an arcane mathematical definition). The effect of their procedure is to select an estimate between the observed average for the individual and the average for all individuals (the fleet average in our case).

The James-Stein estimator gives a large shift away from the individuals observed average when the individual has had only a small number of opportunities. However, the James-Stein estimator gets closer and closer to the individual's observed average as his number of opportunities increase.

These properties of the James-Stein estimators are appealing, even without a rigorous mathematical justification. For example, the overall average fleet experience with a certain missile might be 100 successes out of 200 opportunities. The fleet average is then a .5 success rate. If no drastic changes in hardware or training were to be introduced, we would expect the overall success rate to remain near .5. However, we would also expect some variations between individuals. Thus, some aircrews (or squadrons) may have success rates that are substantially above or below .5. However, we would hesitate to attribute continued perfect performance to an aircrew that scored one success in one opportunity (or 2 for 2, or even 5 for 5). However, we would be inclined to believe that such an aircrew was somewhat above average. The James-Stein procedure selects a value greater than .5 and less than 1.0 for the estimated success rate.

As a second example, suppose that another aircrew accumulated 80 successes in 100 opportunities. We would believe that such a crew has a performance near .8. However, it would not be unreasonable to adjust this value slightly downward (toward the fleet average of .5) to allow for possible random factors. In this case, the James-Stein procedure would give a performance estimate less than, but very close to, .8.

Many of the PORA report formats are illustrated in the main text. Computer-generated reports for individual pilots

are in the formats of Table 7 to 9. Other reports for the squadron and higher levels are in the formats of Tables 10 and 12. Other computer-generated reports are summarized in Tables 2 and 3.

A full set of computer-generated PORA reports are available. However, they are being given limited distribution, to protect the names of individual pilots and squadrons in PORA reports distributed outside the squadron.

ANNEX C-3

CALCULATIONS SUPPORTING TABLE 7

Table 7 of the main text gives estimates of the number of attacking enemy bombers that can be killed by F-14 squadrons providing FORCECAP. This annex explains how the data from Tables 5 and 6 have been combined to produce these estimates. We use the performance data for VF-1 as our example.

Table 5 shows that VF-1 is able to meet its requirement to fly two FORCECAP sorties on each cycle of the day. However, this squadron is unable to meet the requirement that these sorties all be flown by fully mission capable aircraft. Ten percent of its FORCECAP sorties are expected to be merely mission capable (MC), and 90 percent FMC. These two values are shown in the second and third columns of Table 7.

Table 6 shows VF-1's success rates with three missiles (from unclassified contrived data similar to those available in the FOX ONE data base). These are .60 for Phoenix, .90 for Sparrow, and .21 for Sidewinder. We combine these two sources of performance data as follows.

In this scenario, only the CAP aircraft in the sector crossed by the bombers has a Phoenix opportunity. The MC fighters are unable to shoot Phoenix. However, the FMC fighters have a kill probability of .60 per Phoenix missile. Each FMC fighter is assumed to attempt two Phoenix firings. Thus, VF-1 can expect to kill $1.08 (2 \times .90 \times .60)$ bombers, if they approach the battle group through a sector assigned to VF-1.

We have assumed that the aircraft in the penetrated sector, and the second VF-1 aircraft (assumed to be in an

adjacent sector) each have one Sparrow and one Sidewinder opportunity against the bombers. VF-1 can, therefore, expect to kill 1.80 ($2 \times .90$) bombers with Sparrow and 0.42 ($2 \times .21$) with Sidewinder. We have assumed that both aircraft are MC and can shoot these missiles.

We then estimate VF-1's performance in force defense as 3.30 kills in this scenario. The calculation would, of course, be slightly different in other scenarios. However, the PORA approach is to give performance estimates for all squadrons in a common scenario (to be selected by the operational commander).

ANNEX C-4

CALCULATIONS SUPPORTING TABLE 11

In this annex we show how the results of Table 5 (sortie generation) and the ACM results of Table 10 are combined to give an overall MOP in Table 11 of the main text. We illustrate by following the calculations for VF-2.

Table 5 showed that VF-2 can fly an average of 3.92 escort sorties per day (after meeting its higher priority FORCECAP obligations). Thus, VF-2 can produce a section of escorts 1.96 times per day (second column of Table 11). Because VF-2's sister squadron is responsible for escorting half of the seven daily strikes, VF-2 must try to escort 3.5 strikes with 1.96 sections. Thus, an average of 1.54 strikes nominally protected by VF-2 are unescorted.

Table 10 shows that VF-2 kills the enemy with probability .5 in 2v1 encounters (third column in Table 11). Therefore, the enemy interceptor is killed in half of the 1.96 escorted strikes. In other words, the interceptor is killed in .98 attacks (fourth column in Table 11), and it penetrates in .98 attacks. Thus a total of 2.52 (1.54 plus .98) of the 3.5 strike groups are attacked by interceptors on the average day. This total of 2.52 is in the final column of Table 11.

ANNEX C-5

CALCULATIONS SUPPORTING TABLE 12

In this annex we discuss Table 12, where the results are based on a slightly more complicated situation than that of Table 11. Figure C-5-1 is a flow diagram to help the discussion of the calculations. Calculations here are based on the average fleet squadron. In this situation, only half of our strike groups are attacked, but two interceptors participate when there is an attack. Thus, we must draw on ACM performance in 2 v 2 encounters (vice 2 v 1 encounters in the simpler situation of Table 11 and Annex C-4).

The leftmost box shows that the squadron must try to protect 3.5 strike groups and that 3.5 interceptors will attack per day. This box also shows that the average F-14 squadron flies 5.91 escort sorties per day (see Table 5).

As we move to the right, the first branch reflects the enemy's strategy of committing all of its interceptors to half of our strike groups. Thus, 1.75 strike groups are unopposed; but the other 1.75 strike groups are each opposed by a section, totalling 3.5 interceptors. The intercept attempts are chosen randomly by the enemy, so half (2.96) of our escorts are allocated to unopposed strikes and half to opposed strikes.

In the next column of boxes, we have no need for further consideration of the unopposed strike groups. However, we divide the opposed strikes into those with escort and those without. The former category consists of 1.48 strike groups, each opposed by two interceptors and escorted by two F-14s. The latter category consists of .27 unescorted strikes opposed by .54 interceptors.

In the rightmost column of Figure C-5-1, we examine the

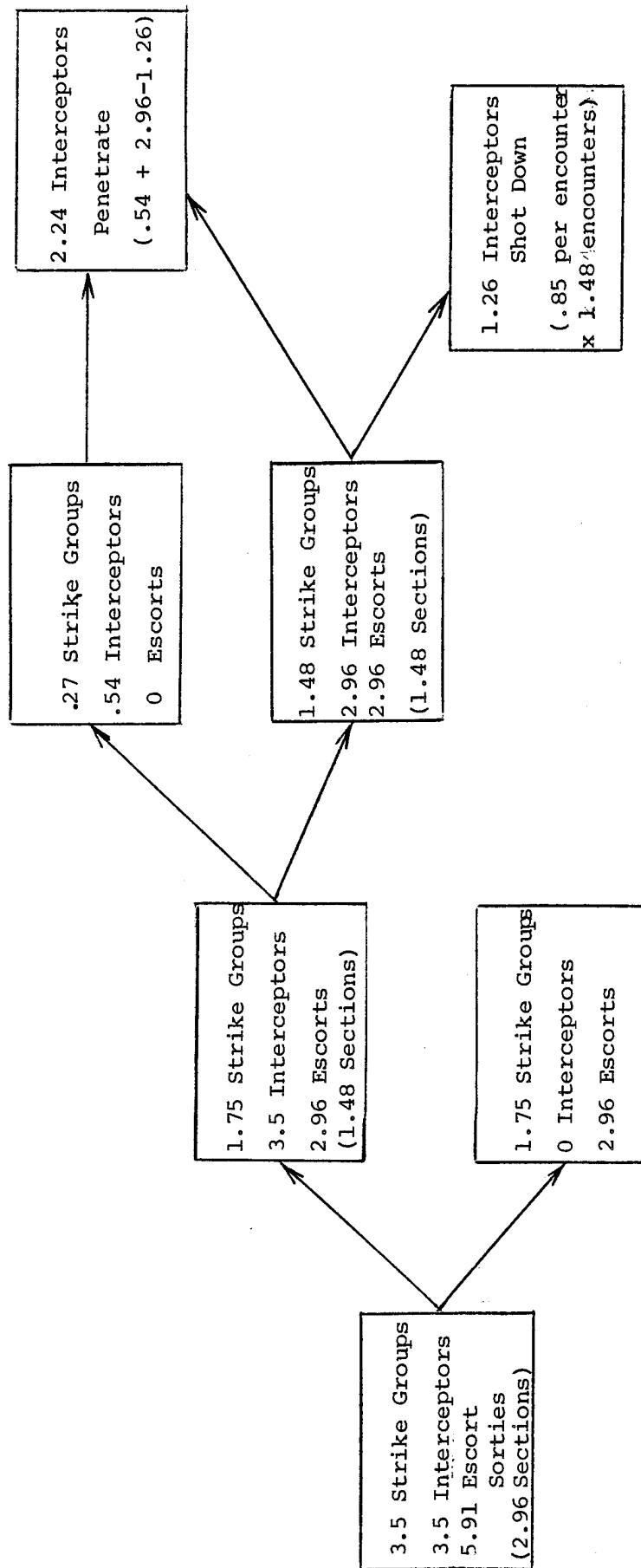


FIGURE C-5-1: 2 v 2 ESCORT EFFECTIVENESS - 2 INTERCEPTORS
PER STRIKE GROUP AGAINST HALF THE STRIKE GROUPS

number of interceptors shot down by escorts. Those not shot down are assumed to penetrate and to attack the strike aircraft. Table 8 shows that an average of .85 interceptors are shot down by the escorts in 2 v 2 encounters. Thus, the escorts shoot down 1.26 ($.85 \times 1.48$) interceptors, while 1.70 ($2.96 - 1.26$) penetrate. An additional .54 interceptors penetrate to the unescorted strikes. In summary, 1.26 of the 3.5 daily interceptors are shot down, and 2.24 interceptors penetrate and attack the strike aircraft.

These results are intended to indicate the relative performance of F-14 squadrons in the escort role. We have not considered attrition on either side.

APPENDIX D
CEP HISTOGRAMS BY BOMBING MODE

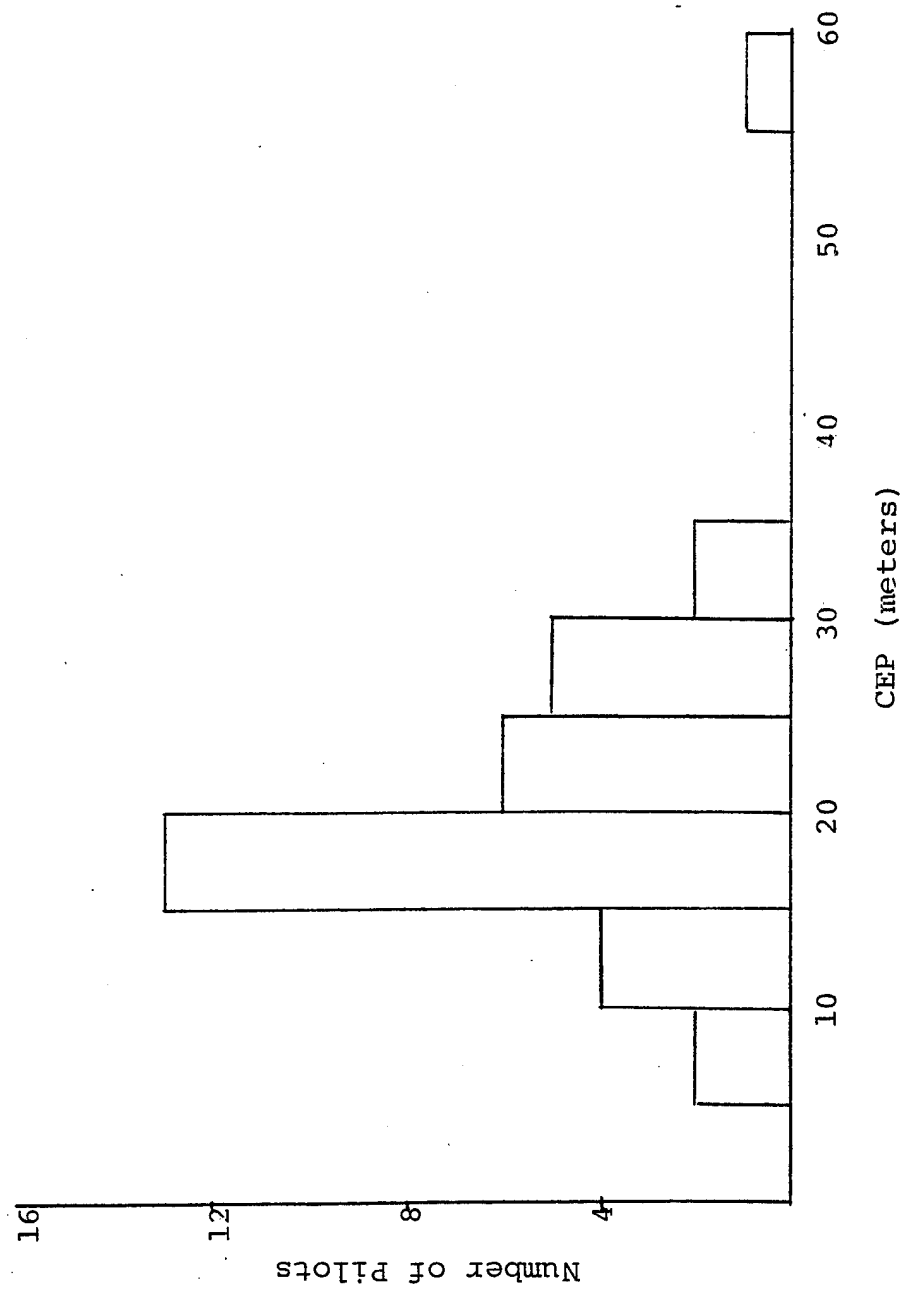


FIGURE D-1: DAY DIVE BOMBING PERFORMANCE DISTRIBUTION

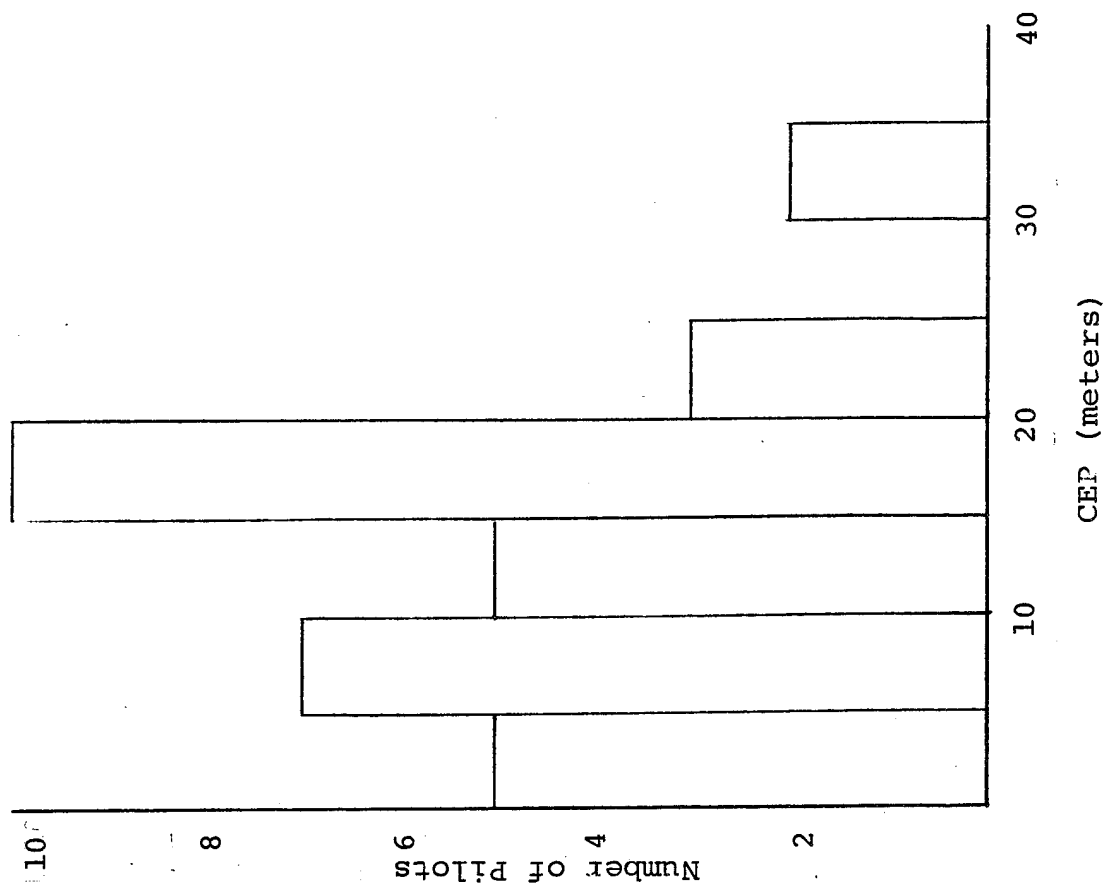


FIGURE D-2: MINIMUM ALTITUDE BOMBING
PERFORMANCE DISTRIBUTION

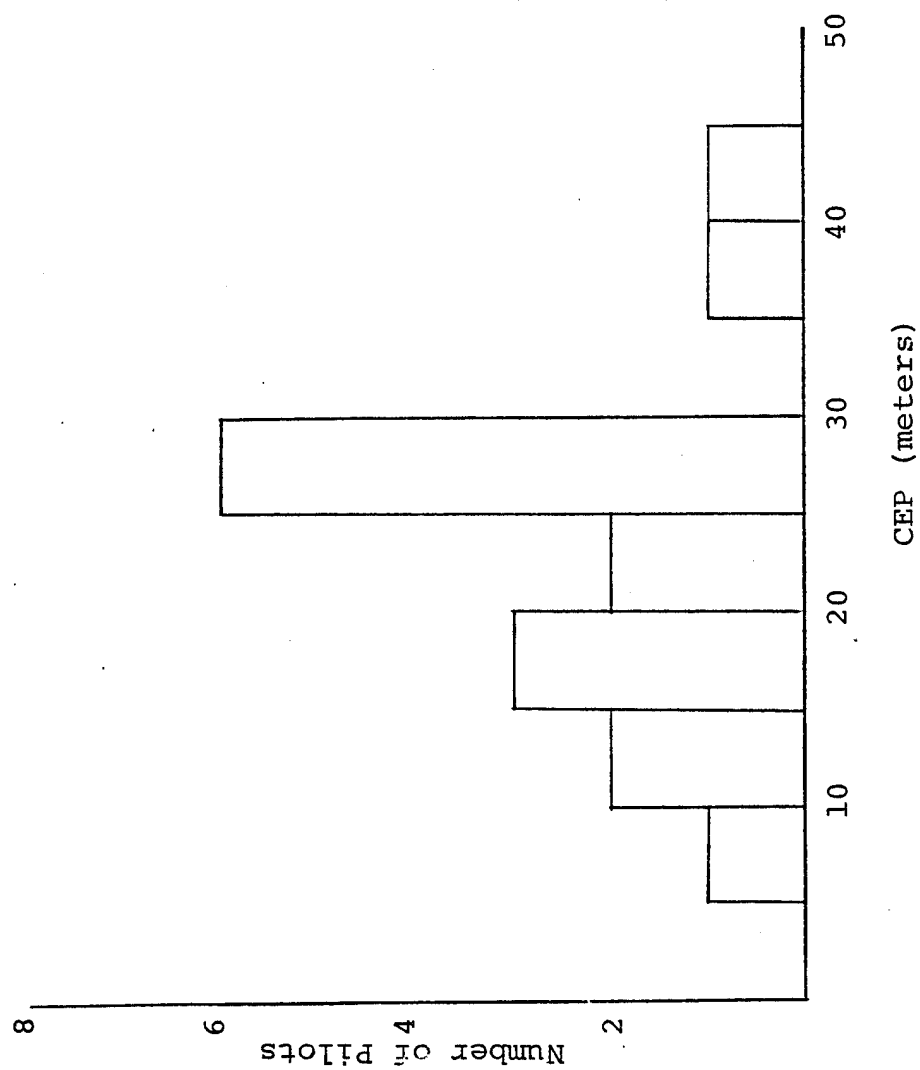


FIGURE D-3: POP UP BOMBING PERFORMANCE DISTRIBUTION

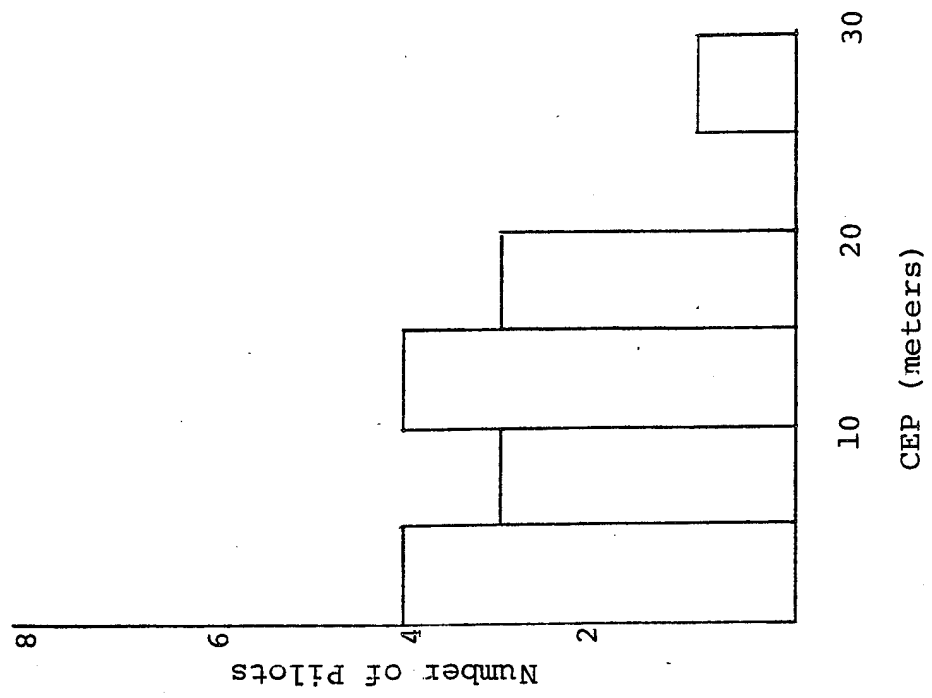


FIGURE D-4: ROLL AHEAD BOMBING PERFORMANCE DISTRIBUTION

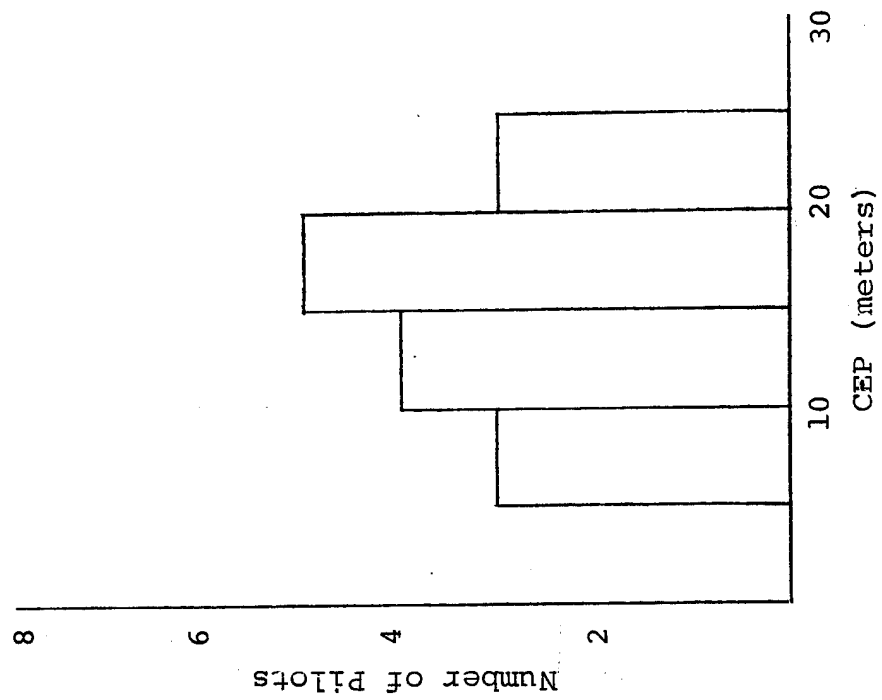


FIGURE D-5: ROCKETS BOMBING PERFORMANCE DISTRIBUTION

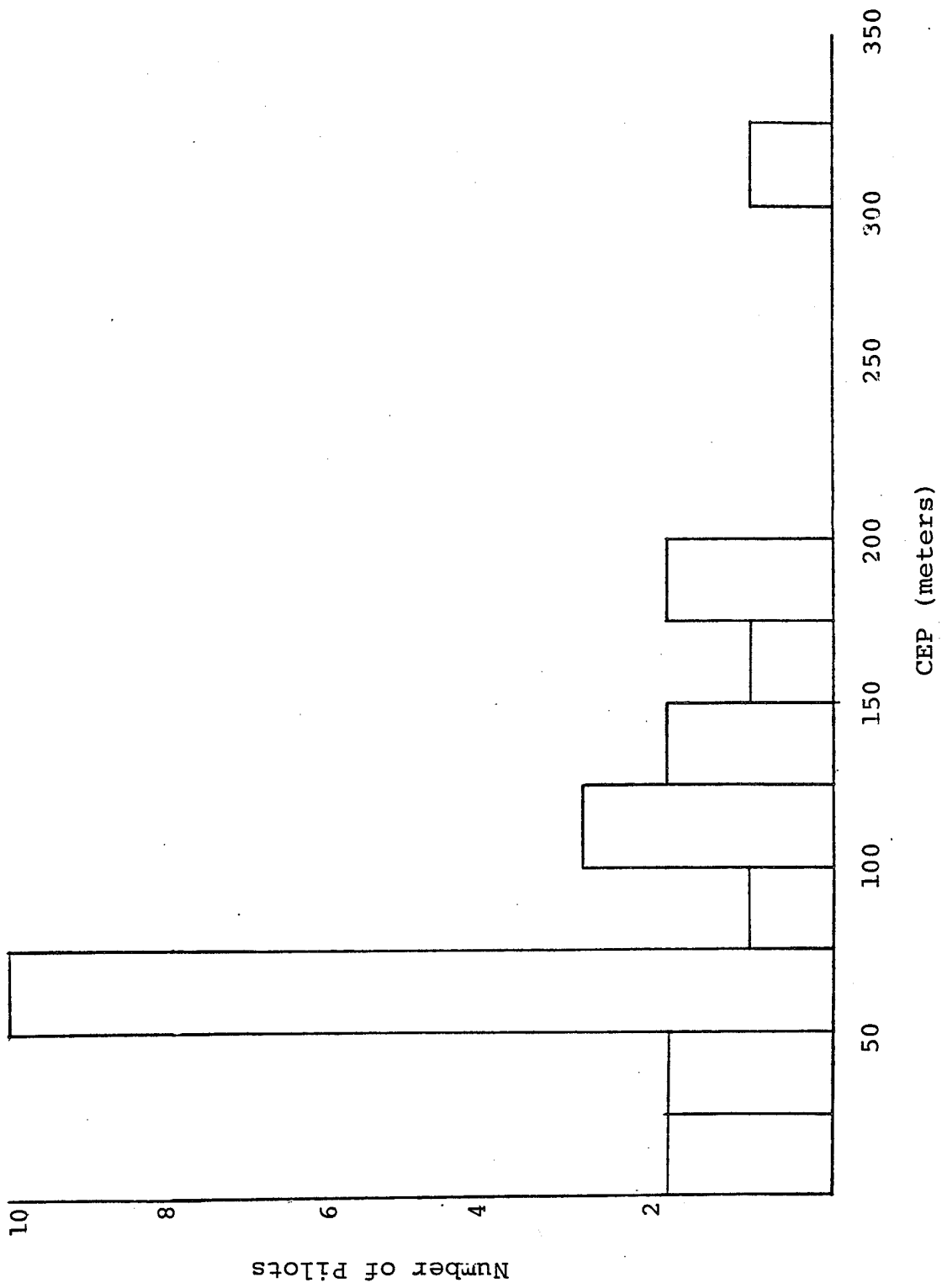


FIGURE D-6: LOFT BOMBING PERFORMANCE DISTRIBUTION

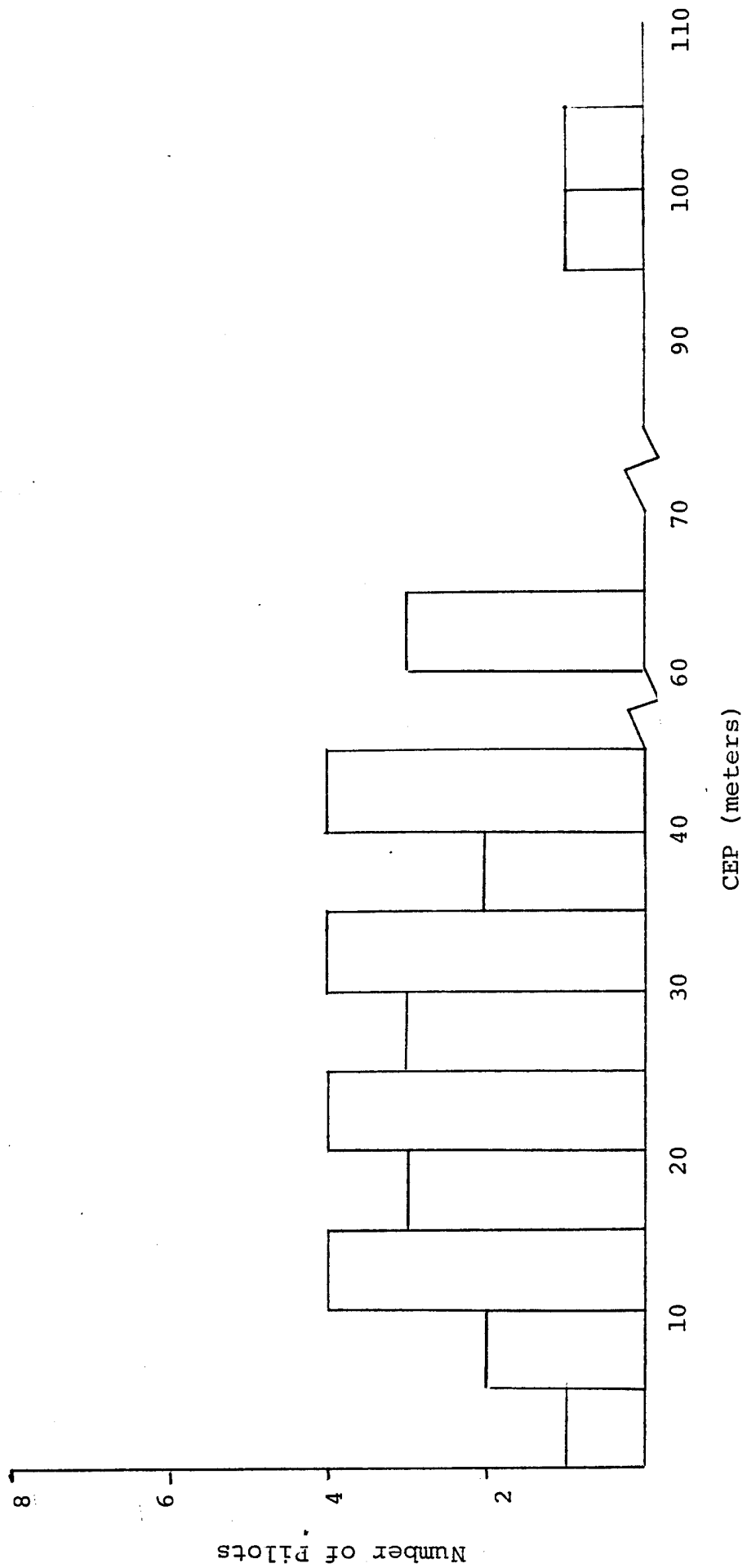


FIGURE D-7: LAYDOWNS BOMBING PERFORMANCE DISTRIBUTION

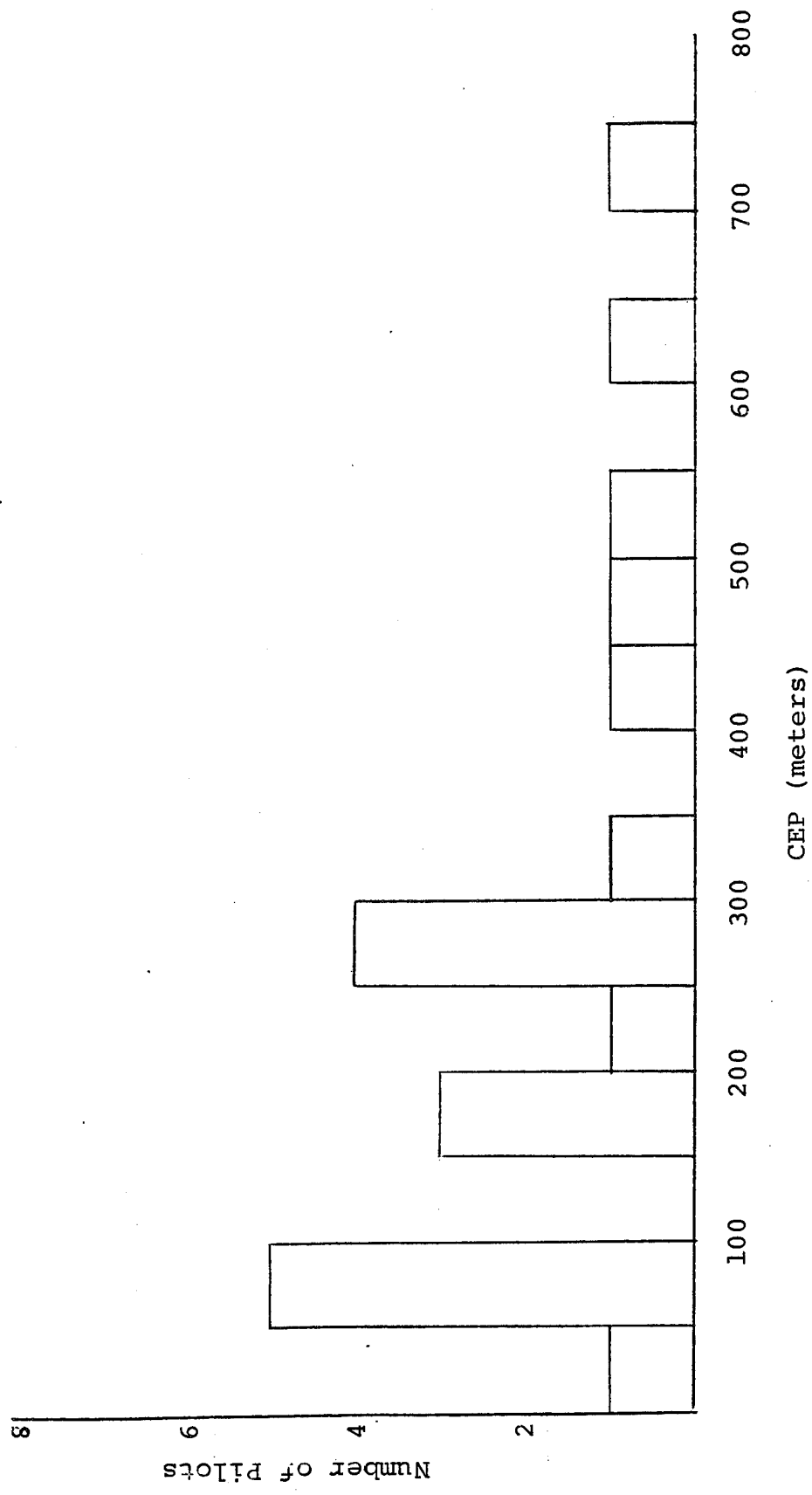


FIGURE D-8: OVER-THE-SHOULDER BOMBING PERFORMANCE DISTRIBUTION

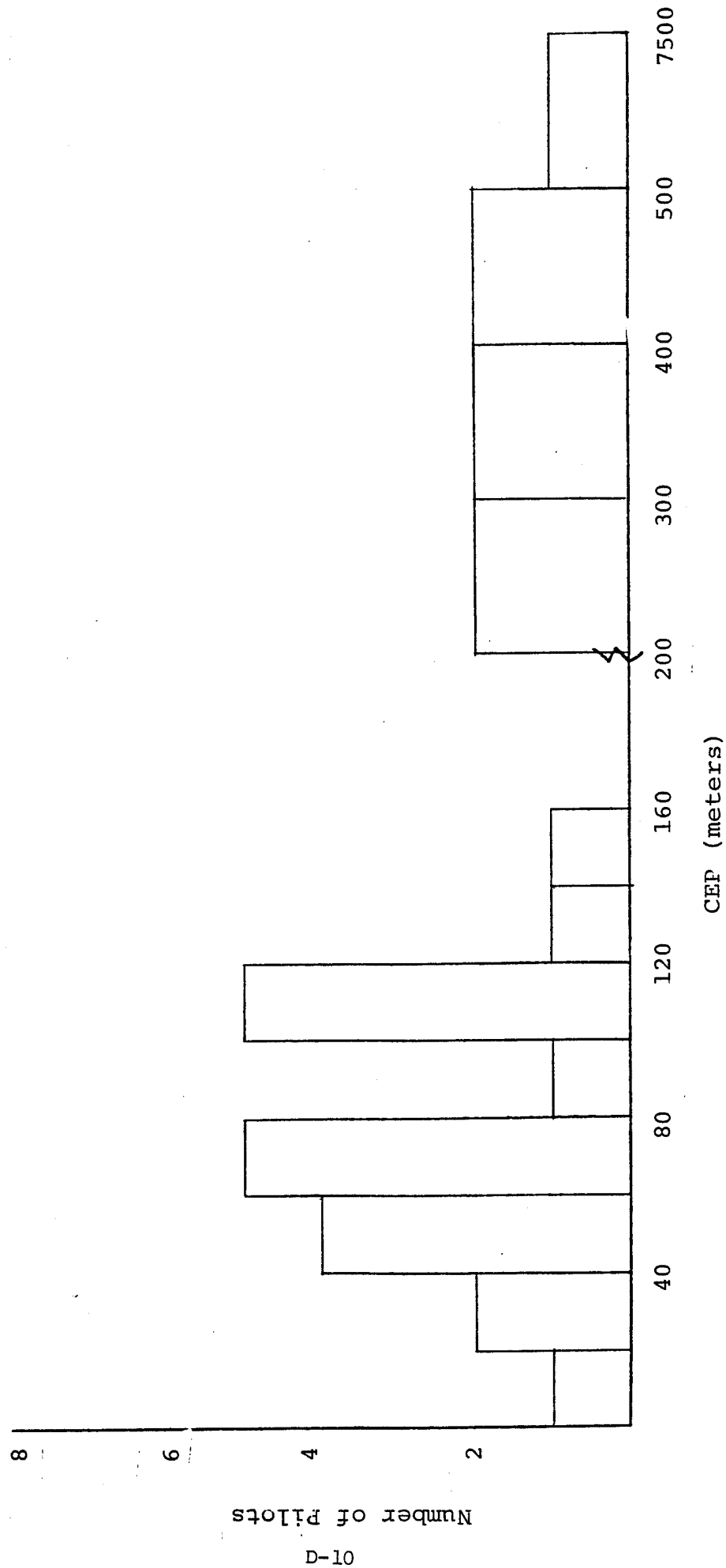


FIGURE D-9: RADAR BOMBING PERFORMANCE DISTRIBUTION

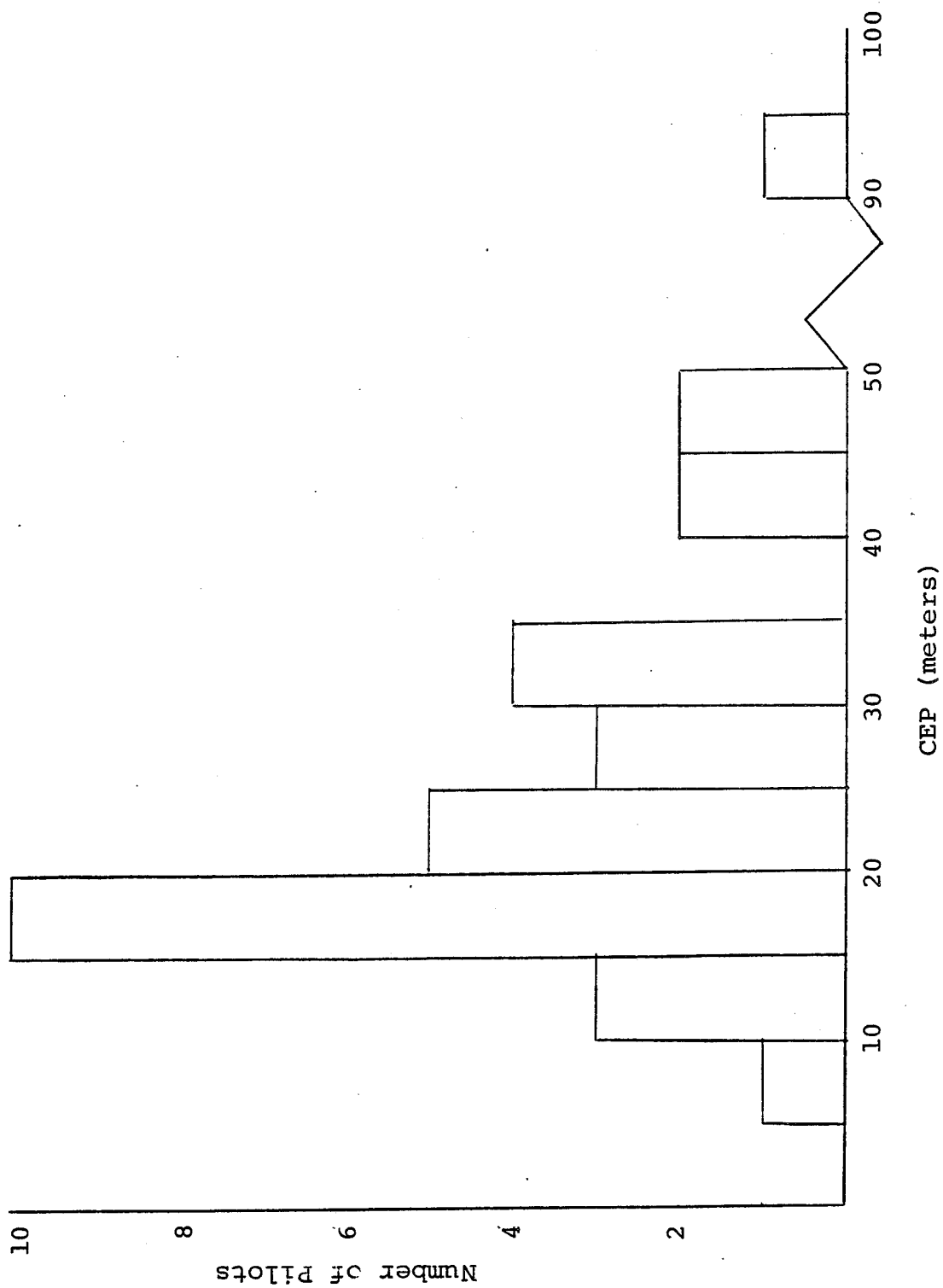


FIGURE D-10: NIGHT DIVE BOMBING PERFORMANCE DISTRIBUTION

APPENDIX E
REPORT DATA ON THE TWO TEST A-7 SQUADRONS
(distributed under separate cover)